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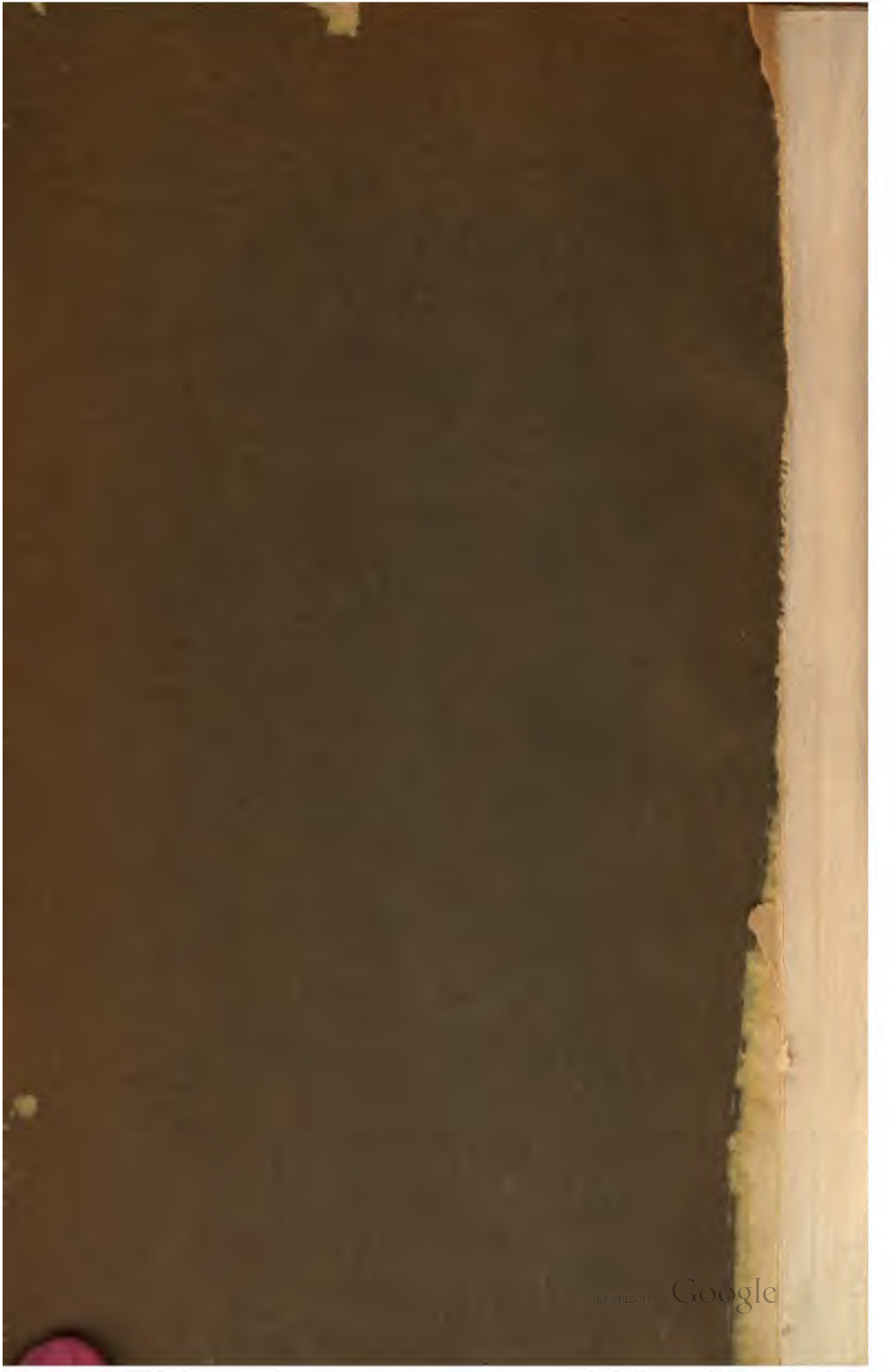
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PORTLAND CEMENT

ITS

MANUFACTURE, TESTING, AND USE

BY

D. B. BUTLER

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PREFACE.

FROM the number of inquiries he has received during the past four or five years, the author has been encouraged in the belief that an up-to-date treatise on the Manufacture, etc., of Portland Cement would be appreciated by those interested in the subject; and in preparing this work he has endeavoured to give a practical description, based mainly on personal experience, of what its title implies, viz. the Manufacture, Testing, and Use of Portland Cement.

Many points have doubtless been mentioned which, to the experienced manufacturer or user, may seem superfluous, but to have omitted them altogether would have rendered the work less complete, and therefore less valuable, to those with a limited knowledge of the subject; the author, however, is sanguine enough to cherish a hope that even those who are well informed may be able to glean a few hints of value.

PORTLAND CEMENT TESTING WORKS
AND LABORATORY,
41 OLD QUEEN STREET, WESTMINSTER.

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PREFACE

TO

THE SECOND EDITION.

IN the six years that have elapsed since the first edition of this work was published, the greatest change that has taken place in the method of manufacture has been the introduction of the Rotary continuous kiln, of which at that time there was not a single installation in England, although it had proved a marked success in America; and since it is undoubtedly the kiln of the future, a considerable space has been devoted to it in the present edition. With regard to grinding machinery, some types have now become more or less obsolete, but as they are all still in use to a limited extent, it has not been thought worth while to eliminate them from the work altogether.

The part devoted to methods of testing has been brought up to date, while to the Appendix has been added a table of Useful Memoranda for the Testing Room, and also a complete copy of recently issued British Standard Specification; the author hopes that with these few alterations and additions, the usefulness of the work will be materially enhanced.

PORTLAND CEMENT TESTING WORKS
AND CHEMICAL LABORATORIES,
41 OLD QUEEN STREET, WESTMINSTER.
October 1905.

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PORTLAND CEMENT.

MANUFACTURE.

CHAPTER I.

INTRODUCTORY.

PORTLAND CEMENT was the name given by Joseph Aspdin, a Leeds bricklayer, to the artificial cement which he patented in 1824, owing to its fancied resemblance in colour and texture to the famous building-stone quarried at Portland. This cement, as he originally prepared it, was obtained by lightly calcining a mixture of lime and clay, and grinding the product; a factory for its production was established by him at Wakefield in 1825, and we read of the cement being employed in the Thames Tunnel by Sir I. K. Brunel in 1828.

It is hardly necessary to add that this cement differed very considerably from the Portland Cement of the present day, inasmuch as the calcination was not carried to that point of incipient vitrifaction which is now recognised as the essential feature in cement burning, in order to convert the mechanically mixed raw materials into the requisite chemical compounds. All the earlier experimenters seemed afraid of pushing the calcination to clinkering point, and some of them even took the trouble to carefully pick out and reject all those portions which showed signs of commencing

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to vitrify, and which, according to modern knowledge and experience, were the most valuable products of the kiln.

Two years after the registration of Aspdin's patent, viz. in 1826, Major-General Sir C. W. Pasley, who had been appointed lecturer on architecture, etc., at the military school at Chatham, commenced his experiments and researches at Chatham Dockyard, and it appears that he was not aware of the existence of Aspdin's cement until some years later. Pasley's aim was to produce an artificial hydraulic cement which should be equal or superior to the natural or Roman cements, at that time about the only hydraulic cements available; and in 1830 he succeeded in producing a very good article, which he used for various experimental purposes with perfectly satisfactory results.

The materials he used were Medway clay and the chalk found in the neighbourhood, though the use of the former was entirely owing to chance. His preliminary experiments had been made with chalk and brick loam, procured from the neighbouring parish of Darland, and as they did not lead to any satisfactory results the matter was abandoned. Some time afterwards, in order to satisfy the wish of a brother officer, who had come to examine his methods of testing natural cements and limestones, he recommenced his experiments. His stock of brick loam being exhausted, he gave orders to the soldier who was employed in the experiments, to use ordinary clay, and, by a fortunate chance, the blue Medway clay was made use of, which at that time was used by the Engineers for securing their fuses in military mining. The results obtained in that series of experiments were so satisfactory, as to induce Pasley to again take up his researches in the matter, in which he afterwards achieved considerable success.

Contemporarily with Pasley at Chatham, Frost estab-

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lished a factory at Northfleet for the production of artificial cement, and his works, which were afterwards taken over by Messrs. Francis and White, were the forerunners of the great factories now forming a staple industry in that neighbourhood.

The chief competitor of the infant Portland Cement industry at that time was the so-called Roman cement, produced by lightly calcining and grinding the septaria nodules found in the Isle of Sheppey and elsewhere; and as this was a very profitable business, it is easy to understand that the new cement was strenuously opposed. The new material, however, gradually gained ground in the confidence of engineers and others, and, as its quality improved, it by degrees drove the natural cement out of the market for all important work, though Roman cement is even now considerably used where a very quick setting hydraulic cement of no great strength is required. The experiments of the late Mr. John Grant, of the Metropolitan Board of Works, in connection with the London drainage works, in 1859, subsequently gave the industry a great impetus; and both manufacturers and users of Portland Cement are largely indebted to him for the knowledge they now possess of the properties and peculiarities of this important constructive material.

Although at the present time there is still room for much improvement, the method of manufacture of Portland Cement in the early days was of the crudest possible description. Crushers of the familiar type now in use were then unknown, and instead of the present method of mechanically crushing the clinker, and raising it by means of elevators to the required height for feeding into the grinding machinery, the material as it came from the kilns was broken with a hammer small enough to be fed into the millstones, and then placed in sacks for conveyance to the

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millstone hopper. The ground material as it came from the stones, if it was stored in the warehouse at all, was wheeled away in barrows, and piled into a heap with infinite labour ; and what was considered well-ground cement in those days, would now be scornfully rejected by the veriest speculative builder.

The first important labour-saving improvement was the adoption of the semi-wet process of mixing the chalk and clay, patented by Goreham in 1872. By this process a much smaller quantity of water is used for the preliminary mixture of the raw materials, the final combination being effected by passing the rough mixture through millstones ; the thick slip is then conveyed by pumps direct on to the drying floors or kiln drying chambers, thus saving the labour consequent on having to dig the mass out of the settling backs and wheel it to the drying floors, which was entailed by the older wet process. A further economy in cement production was Johnson's patent kiln, which utilised the waste heat from the calcination of the clinker for the drying of the next load of slurry, thus doing away with separate drying floors and their consequent expense in fuel consumption. There is probably something to be said both for and against this method of drying slurry, but, as it has been almost exclusively adopted in some form or other by cement makers throughout the kingdom, there is not much doubt that it is a success from an economical point of view, if not from the quality of the resulting clinker. Labour-saving devices of all kinds have now come into general use, and, except in loading and drawing the kilns, the former of which under present conditions necessitates skilled labour, the material is not touched by hand from the time the raw materials are placed in the wash-mill till the finished cement is delivered into the warehouse, ready for despatching to the consumer. The recent introduction of the rotary con-

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tinuous kiln has even abolished the exceptions above noted, and the manufacturing process can now be accomplished by mechanical means throughout.

The proportions of raw materials used in the manufacture of Portland Cement were in the early days entirely governed by rule of thumb ; a fixed proportion of each was fed into the wash-mill, irrespective of their condition, and although some rough check was kept, by testing the finished cement in a more or less slipshod manner before delivery, if any error occurred in the proportions used, it was not discovered until the whole process was completed and the mischief done. As will be seen in the following pages, the methods now in use for checking and maintaining the correct proportions of the raw materials, enable an accuracy to be attained which in the early days would have been considered little short of wonderful. The aid of the chemist has been enlisted, and by very simple means the proportions of the raw materials and their proper combination are kept in check. Most large manufacturers now employ a trained chémist on their staff, and those whose works are not sufficiently extensive to warrant such expense, at all events recognise the value of having periodical analyses made of both their raw materials and the finished cement.

In consequence of the more exacting demands of the user in that direction, the grinding of cement has been steadily improving during the past few years, and in this particular the English cement trade has made enormous strides during the last few years. It is evident that, apart from the other advantages of fine grinding, the finer a cement is ground the greater the amount of surface it will cover, and therefore the larger proportion of sand or aggregate it will bear. The late Mr. Grant was one of the first to recognise this important feature, and he willingly paid a considerably enhanced price, consequent on the increased cost of pro-

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duction, in order to obtain a material fine enough to meet his requirements.

The present method of testing the quality of cement has been gradually evolved from the researches of the earlier experimenters. Vicat, in his time, was content to test the hardness of his lime mortars after setting, by noting the amount of indentation made by a blunt needle of a certain weight falling upon them from a certain height. Later on, Smeaton tested the hydraulicity of his limes by making them into balls, placing them under water, and noting whether they hardened or disintegrated. Later still, in Pasley's time, the cementitious value of a cement was ascertained by sticking bricks together with it, one at a time, projecting horizontally from a wall, that being considered the best cement which would bear the greatest number of bricks stuck together in this way. Although in some instances a great many bricks were thus joined together, it did not seem to occur to those engaged in such tests that, as nearly all cements increase in strength with age, the time which elapsed between the addition of each brick would materially affect the result. Pasley's own method of testing the artificial cements which he made in his experiments was rather primitive, but certainly practical. After cementing two bricks together, and allowing them a certain time to harden, he suspended them from an artillery gin or tripod, by a pair of nippers or claws fixed to the upper brick ; and placing a similar pair of nippers on the lower brick, attached weights thereto, and ascertained the amount of weight which was necessary to pull the joint asunder ; in some instances he found that his bricks gave way before his cement joint. From these experimental tests doubtless sprang the present method of testing for tensile strain, and the many accurate machines at present in use for ascertaining that property.

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Grant was the first to go thoroughly into the question of cement testing, and his experiments and researches have stamped him as an authority on the subject. The late Henry Faija followed closely after Grant in most things, though he totally disagreed with him as to the utility of the sand test, maintaining that it first involved the testing of the sand, and was valueless as a comparative test unless the same quality of sand could always be guaranteed. Faija was the first to carry out cement testing in a scientific and methodical manner, and many machines are at present in daily use for that purpose which bear his name. He was one of the first to point out the paramount importance of the soundness of cement, viz. freedom from disruptive agencies within itself; for, as he rightly maintained, no matter what excellent qualities a cement may possess in other respects, such as fine grinding and tensile strain, if it contains the germs of disease, so to speak, within itself, and eventually crumbles and disintegrates, it is evidently of no use as a constructive material. Speaking of Portland Cement generally, Faija was wont to express the opinion that if a cement was sound and well ground, it was almost invariably strong enough for any constructive work in which it might be used.

The Portland Cement industry having originated in England, the English manufacturers for some years possessed a practical monopoly of the article, at all events as regards export to non-cement-producing countries; but where suitable materials were found, cement works gradually sprang up on the Continent and elsewhere, and now competition is very keen between English and Continental makers in the foreign and colonial markets.

The table on the following page, which shows the quantity of cement exported from the United Kingdom from 1855 to 1903, and its value, may be of interest. It will

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be seen that the exports showed a steady increase up to 1889, when they began to decrease, and, with the excep-

Year.	Tons.	Declared Value.	Declared Value per Ton.
		£	s. d.
1855	35,193	99,530	56 6
1860	79,217	214,674	54 2
1865	112,876	285,898	50 7
1870	150,444	366,199	48 8
1875	245,982	642,814	52 3
1880	277,490	692,875	49 11
1885	367,895	811,000	44 1
1886	425,880	862,052	40 5
1887	506,090	982,776	38 10
1888	612,700	1,165,000	38 0
1889	631,660	1,231,649	38 11
1890	623,440	1,281,963	41 1
1891	575,969	1,140,697	39 7
1892	492,615	902,910	36 7
1893	437,565	744,424	34 0
1894	425,582	703,389	33 0
1895	395,484	641,551	32 5
1896	353,863	580,518	32 9
1897	391,596	647,191	33 0
1898	326,425	610,723	37 5
1899	352,358	690,835	39 2
1900	359,944	673,162	37 5
1901	305,331	583,974	38 3
1902	303,252	520,512	34 4
1903	399,988	676,752	33 10
1904	384,795	632,557	36 2

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tion of a slight spurt in 1897, continued to do so up to 1903, when another big spurt occurred, which has been fairly maintained during 1904. The author has not been able to obtain reliable statistics as to the total output of cement in the United Kingdom during the same period, but he feels justified in stating that, although the exports show a gradual falling off, the home consumption has so largely increased that the output has been fully maintained. In consequence of the many important harbour and other engineering works then being carried out in this country, the demand for cement was so enormous during the years 1897–1899, that English manufacturers, even after largely extending their works, were unable to cope with it; the result was that a good deal of foreign cement, mostly of Belgian origin, found its way into the country, where it seems to have established a firm footing, judging from the following table of imports.

BELGIAN CEMENT IMPORTED INTO THE UNITED KINGDOM.

Year.	Tons.	Declared Value.	Declared Value per Ton.
		£	s. d.
1896	1,751	2,120	24 2
1897	14,064	18,000	25 7
1898	68,203	93,560	27 2
1899	91,474	126,234	27 7
1900	84,526	114,960	27 2
1901	173,844	291,008	33 5
1902	204,166	328,218	32 2
1903	214,719	326,507	30 5
1904	229,817	—	—

Judging from personal experience these imports consist

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largely of various qualities of "natural" cement, i.e. cement inexpensively produced by the simple calcination and grinding of natural calcareous rocks, which in composition approach more or less closely to that of raw Portland Cement slurry; the term "natural" cement is used in contradistinction to "artificial" Portland Cement, which, as will be seen hereafter, is produced from a carefully and accurately proportioned mixture of chalk and clay or similar raw materials.

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CHAPTER II.

RAW MATERIALS.

PORTLAND CEMENT may be defined as a compound consisting chiefly of silicates and aluminates of lime, produced by the calcination to incipient vitrifaction of a mechanical mixture of chalk and clay, or similar materials containing the requisite chemical constituents, the clinker thus produced being subsequently ground to a more or less impalpable powder. The exact chemical composition of Portland Cement varies considerably; its principal constituents are silica, alumina, oxide of iron, and lime, which, generally speaking, are found in roughly the following proportions :—

Lime . . .	60 to 64 per cent.
Silica . . .	20 „ 24 „
Alumina . .	6 „ 10 „
Iron oxide . .	3 „ 5 „

These four constituents, as a rule, amount together to about 96 per cent., the remainder consisting of small quantities or sulphuric anhydride, magnesia, alkalies, etc.

The process of cement manufacture, as will be seen hereafter, may be divided into three distinct operations, the inefficient performance of either of which materially affects the quality of the product :—

1. The intimate blending or mechanical mixing of the raw materials.

2. The conversion of the mechanically mixed raw ma-

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terials into the requisite chemical compounds by calcination.

3. The pulverisation of the calcined product, to enable it to combine with water and thereby set and harden.

Although Portland Cement may be produced from almost any raw materials containing the requisite chemical constituents, its manufacture to commercial advantage naturally depends upon the physical properties of those raw materials, and the treatment to which they have to be subjected, to enable them to be intimately blended mechanically, in the first instance, before being chemically converted by calcination. The first essential, therefore, from an economical point of view, is that the raw materials shall be easy of reduction to the requisite mechanical mixture; for after this mechanical mixture has been effected, no matter by what means, the cost of the subsequent operations of calcination and grinding is practically the same in every case. For instance, when the materials have to be treated by the wet process of manufacture, it is very evident that a hard chalk will cost more to reduce to an intimate mechanical mixture with the clay than a soft one; and similarly with the dry process, where both materials have to be dried and ground before mixing, those materials which are most easily reduced to the requisite degree of fineness are the most economical to use.

The chief raw materials used for the manufacture of Portland Cement in this country are the chalks and estuary muds which are found in great abundance in the lower reaches of the Thames and Medway, as these materials can be most economically treated in the first operation of mechanical mixing. In the early days of Portland Cement manufacture, Frost and others found that the chalk abounding in this neighbourhood, mixed with the estuary mud of the Medway, was best suited to their purpose; and

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as the demand for the product increased, other factories sprang into existence in the neighbourhood—and thus commenced what is now one of the most important industries of the Thames and Medway. Another factor which probably largely influences the establishment of factories in this district, is the facility of cheap transport by water, both for obtaining fuel supplies for calcination purposes and also for disposing of the manufactured article in the London market, either for home consumption or for export from the various docks.

It very rarely occurs that both the requisite materials, viz. chalk and mud, are to be had on the same site, and as chalk forms by far the greater part of the mixture (roughly, two of white chalk to one of mud, as fed into the wash-mill in the wet state), the factories are generally erected on the river's edge, with chalk supplies from the quarries at the rear, the mud being brought by barges from the beds in the lower reaches of the river. Along the upper reaches of the Medway, in the Burham district, beds of Gault clay crop out, and, in combination with the grey chalk, are extensively used by one or two firms on whose property they occur. It may, however, be stated generally, that cement in the London district is made from the estuary mud, combined with the necessary proportion of chalk.

Referring generally to the following analyses, it will be found that the composition of the cement does not always correspond exactly with the composition of the raw materials. As pointed out at the end of Chapter III., this is largely due to the ash of the coke used for calcination purposes, which mingles with the clinker in the kiln, and as this ash consists largely of silica and alumina, the composition of the resulting cement is somewhat modified. The firebrick lining of the kiln, also, is apt to affect the resulting

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clinker to a greater or less extent, by fluxing and combining with it.

The following analyses, taken from our testing books of 1888, show the composition of the chalk and mud used on the Essex shore of the Thames, and also of the cement produced therefrom.

CHALK.

Water, 23·00 per cent.

Insoluble silicious matter . .	·85
Silica	·35
Alumina	·75
Carbonate of lime . . .	98·12
	100·07

The above sample was taken from the top strata of the pit. Samples from the middle and bottom strata contained as follows:—

	Middle.	Bottom.
Carbonate of lime . .	98·85 per cent.	98·07 per cent.

ESTUARY MUD.

Roughly dried, lost 33·33 per cent.

Water	2·63
Organic matter	4·06
Silica	60·30
Alumina	11·07
Oxide of iron	8·13
Carbonate of lime . . .	7·85
„ magnesia . . .	2·66
Sulphuric acid	2·50
Alkalies	·45
	99·65

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CEMENT.

Water and carbonic acid . .	1·40
Silica	23·30
Alumina	5·85
Oxide of iron	4·65
Lime	60·90
Magnesia	·90
Sulphuric acid	2·43
Alkalies	·30
	99·73

The manufacturers on the Kent shore of the Thames use the chalk at the rear of their works, in combination with the estuary mud, of which the following analyses, extracted from our testing books of 1881, may be taken as examples. The analysis of the cement following is also that of one manufactured on the Kent shore, but as the sample was made in 1896, it can scarcely be said that the materials quoted were used in its production.

MUD.

	Samples: Nos.		
	1	2	3
Organic matter and water .	6·32	5·39	4·31
Silica	71·71	62·41	74·50
Alumina . . .	6·42	18·09	10·45
Oxide of iron . . .	10·28	10·35	6·30
Carbonate of lime . .	4·05	1·63	1·78
Alkalies. . . .	1·10	2·10	2·50
	99·88	99·97	99·84

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CHALK.

Silica	1·02
Alumina and iron oxide . .	·72
Carbonate of lime . . .	97·36
Water	·91
	100·01

CEMENT.

Water and organic matter . .	2·05
Insoluble residue	·77
Silica	21·72
Alumina	7·83
Oxide of iron	4·31
Lime	60·79
Magnesia	1·00
Sulphuric acid	1·10
Alkalies and loss	·43
	100·00

The following analyses, taken from our testing books of 1892, give the composition of the blue Gault clay from the upper reaches of the Medway, the chalks used in combination with it, and the cement produced therefrom :—

BLUE GAULT CLAY.

Organic matter	1·30
Sand	9·64
Combined silica	34·06
Alumina	15·09
Oxide of iron	5·76
Lime	15·25
Magnesia	2·02
Sulphuric acid . . .	1·64
Carbonic acid	14·20
Potash	·38
Soda	·26
	99·60

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CHALKS.

	White.	Grey.
Insoluble silicious matter. .	1·50	3·95
Soluble silica . . .	·10	·20
Alumina and oxide of iron .	·80	·75
Carbonate of lime . . .	97·32	94·37
Potash.	·22	·18
Soda	·16	·13
Magnesia	trace	trace
Sulphuric acid . . .	trace	trace
	100·10	99·58

CEMENT.

Water	·70
Carbonic acid	trace
Silica	21·05
Alumina	8·95
Oxide of iron	4·40
Lime	61·30
Magnesia	1·37
Sulphuric acid	1·57
Potash	·37
Soda	·31
	100·02

As an example of the Medway chalk and estuary mud and the cement produced from them, the following analyses, taken from our testing books of 1888, may be quoted :—

MEDWAY CHALK.

Roughly dried, lost 11·66 per cent.

Loss at 212°	·40
Insoluble silicious matter . .	3·45
Silica	·65
Alumina and oxide of iron . .	3·35
Carbonate of lime . . .	92·23
	100·08

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The foregoing sample was taken from the upper strata of the pit; the samples from the middle and bottom strata containing as follows:—

	Middle.	Bottom.
Carbonate of lime . .	90·90 per cent.	90·22 per cent.

MEDWAY MUD.

Water	4·30
Organic matter	7·49
Silica	54·80
Alumina	14·40
Oxide of iron	8·10
Carbonate of lime	4·64
„ magnesia . . .	3·50
Sulphuric acid	1·69
Alkalies	0·75
	99·67

CEMENT.

Loss at 212°.	·20
„ red heat	2·20
Silica	22·80
Alumina	6·49
Oxide of iron	4·31
Lime	61·10
Magnesia	·47
Sulphuric acid	1·71
Alkalies	·30
	99·58

Scattered round our coasts, wherever there is a demand for Portland Cement, or where special facilities occur for its manufacture, there are factories using chalk and clay as the basis of their manufacture. At Newcastle and Hull, especially, there are factories which use a local clay in combination with chalk imported from the London district;

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in the earlier days of the industry, the chalk was brought back as ballast by the colliers plying between the northern coal-fields and the metropolis, but by far the greater part is now conveyed by vessels specially employed for that purpose.

The following is an example of the composition of the local clays found at Hull :—

CLAY.

Organic matter and moisture . .	5·10
Sand	17·20
Combined silica	34·29
Alumina	21·55
Oxide of iron	7·09
Carbonate of lime	6·41
„ magnesia . . .	4·07
Sulphuric acid	2·32
Alkalies and loss	1·97
	100·00

It will be seen that these clays are apt to be rather sandy ; but the sand is as a rule extremely fine, and when used with the following chalk, the resulting cement leaves nothing to be desired in point of quality, its analysis being as given on next page.

CHALK.

Loss after being dried at 212° F., 21·69 per cent.

The dried sample contained—

Silica	1·61
Alumina	·40
Carbonate of lime	97·45
Alkalies	·51
	99·97

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CEMENT.

Water and carbonic acid . . .	1·65
Insoluble residue	·87
Silica	21·17
Alumina	7·35
Oxide of Iron	4·14
Lime	61·94
Magnesia	·91
Sulphuric acid	1·38
Alkalies and loss	·59
	100·00

The somewhat sandy clay previously quoted, inclines the author to the belief that an extremely fine sand will not materially affect the quality of the cement, provided the clinker is thoroughly calcined. The very small amount of insoluble residue in the above cement, shows pretty clearly that the silica and alumina contained in the fine sand has combined with the other constituents on calcination. It may be mentioned, in passing, that one disadvantage arising from the use of a sandy clay, though it is a purely mechanical one, is that it tends to make the dried slurry rotten and friable, and is thus apt to cause dusting and choking of the kilns.

At several places on the south coast where chalk supplies are abundant, there are cement manufactories using a local chalk, either with imported clay, or with that found in the neighbourhood.

The following analyses may be given as examples of the chalk found in the Portsmouth district, the estuary mud found in the neighbourhood, and the cement produced therefrom :—

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CHALK.

Silica	·90
Alumina and oxide of iron	·20
Carbonate of lime	98·50
Alkalies and loss	·40
	100·00

CLAY.

Water	2·30
Organic matter	6·00
Silica	58·70
Alumina and oxide of iron	21·40
Carbonate of lime	10·30
Alkalies and loss	1·30
	100·00

CEMENT.

Water and carbonic acid	1·90
Silica	25·20
Alumina and oxide of iron	9·90
Lime	60·70
Magnesia	·60
Sulphuric acid	1·50
	99·80

Next in importance to the chalks and clays as cement-making materials are the Blue Lias formations of Warwickshire and elsewhere. By judicious blending of the stones and shales of these formations, an excellent Portland Cement is produced. These materials, however, being of a less easily reducible nature in the first operation of mechanical mixing, require to be treated by what is known as the dry process, viz. ground in a dry state between millstones or other convenient machinery, to enable them to be intimately blended. This process of manufacture, taken in conjunction with the considerably greater cost of getting the raw materials, renders the cement more expensive to manufacture than that produced from chalk and clay by

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the wet process, and it may therefore be stated generally that the cement thus manufactured in the Midlands is consumed locally, in contradistinction to the great export factories of the Thames and Medway. The following analyses, taken from our testing books of 1893, may be quoted as showing the composition of blue lias stone and shale, and of the cement produced therefrom :—

Lias Stone.	
Silica	8·73
Alumina and oxide of iron . .	8·78
Lime	43·95
Magnesia	1·87
Sulphuric acid	·74
Alkalies	trace
Carbonic acid	36·20
	100·27
Lias Shale.	
Organic matter	3·72
Silica	30·05
Alumina	10·70
Oxide of iron	3·30
Lime	26·80
Magnesia	3·68
Sulphuric acid	1·43
Carbonic acid	20·08
Potash	·19
Soda	·13
	100·08
Cement.	
Water and carbonic acid . .	1·10
Silica	19·78
Alumina	8·21
Oxide of iron	4·53
Lime	62·69
Magnesia	2·09
Sulphuric acid	1·57
	99·97

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The above analysis of lias stone is the average of samples taken from seventeen different layers or floors. The stone and shale are found interstratified, in layers ranging in thickness from two inches to two feet, each layer varying considerably in composition, so that careful blending is necessary in order to obtain the correct proportions.

The following table gives the average thickness and the percentage of carbonate of lime in each of the different floors mentioned above :—

No.	Average Thickness. Inches.	Percentage of Carbonate of Lime.	No.	Average Thickness. Inches.	Percentage of Carbonate of Lime.
1	5	78·95	10	4	84·48
2	4½	75·94	11	4½	79·59
3	2½	79·74	12	6	78·38
4	3	82·34	13	2	76·34
5	4½	80·44	14	5	76·75
6	4	82·81	15	4½	82·24
7	5½	82·61	16	4½	80·83
8	3	80·95	17	7	75·74
9	14	78·84			

In Wales and elsewhere, where suitable limestone and shale, or limestone and clay are to be found, there are small factories erected to supply local demands. The following analyses, taken from our testing books of 1884, show the composition of some of the Welsh limestones and clay, and of the cement resulting therefrom :—

LIMESTONES.

Silica	1·025	4·350	1·95	1·20	1·25	1·35
Alumina	trace	trace	0·65	1·00	0·525	1·90
Carbonate of lime	97·70	94·575	77·8	81·825	90·00	88·15
Carbonate of magnesia	0·499	0·625	19·507	16·809	8·68	10·575

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CLAY.

Silica	58·557
Alumina	15·255
Oxide of iron	4·995
Carbonate of lime . . .	11·425
,, magnesia . . .	6·239
Alkalies	2·728
Ogranic matter and loss . .	·801
	100·000

CEMENT.

Loss at 212°	·30
Silica	22·20
Alumina	12·45
Lime	57·40
Magnesia	5·98
Sulphuric acid	1·13
Alkalies	·81
	100·27

It will be noticed that these materials contained a varying but considerable quantity of magnesia, often resulting in a decidedly uncomfortable quantity of that constituent being present in the finished cement; they also had to be treated by the somewhat more expensive dry process of manufacture. A white marl deposit was subsequently found in the neighbourhood, which, as will be seen from the following analysis, contained no magnesia, and which could be treated in the wash-mill by the wet process; it was therefore substituted for the limestone, with satisfactory results. It was, however, rather inclined to be rough and gritty, even after treatment by the wet stones, the grit apparently consisting of small nodules of carbonate of lime, and this gritty nature was the source of considerable trouble. The resulting cement was, however, a vast

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improvement on that produced from the limestone, and of course by the wet process the cost of reduction was materially less. The analyses of the marl, of the clay used with it, and the cement produced from them are given below :—

MARL.

Silica	·05
„ (insoluble)	·15
Alumina	·50
Carbonate of lime . . .	98·57
	99·27

CLAY.

Carbonic acid	7·39
Silica	51·82
Alumina and oxide of iron . .	28·43
Lime	5·19
Magnesia	3·01
Sulphuric acid	1·18
Water and organic matter . .	2·49
	99·51
Alkalies and loss	·49
	100·00

CEMENT.

Loss at red heat	1·50
Lime	61·25
Silica	21·20
Alumina and oxide of iron . .	11·40
	95·35
Alkalies, etc. (not estimated) . .	4·65
	100·00

In Cambridgeshire and elsewhere natural marls are

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found, the chemical constituents of which approximate very nearly to that of raw slurry, i.e. Portland Cement before calcination. The earliest method of utilising these deposits for cement-making purposes, was to simply calcine the raw material as it came from the pits, without any mixing or blending. Owing to the varying and uncertain nature of the various strata, the resulting cement was altogether unreliable, and therefore this method had to be abandoned. The more recent method is to thoroughly mix and blend the marls, by passing them through a wash-mill in the ordinary way, sometimes with the addition of a small quantity of the chalk found in the neighbourhood. During the last few years these deposits have also been most successfully and economically treated by the dry process, the somewhat soft nature of the marl rendering it peculiarly adapted for grinding and mixing in the dry state.

The unreliable nature of the cement produced by the direct calcination of the deposits in the earlier attempts, gained a rather unenviable notoriety for the cements made from the Cambridgeshire marls, and, judging from samples that came under the author's notice some twenty years ago, it certainly was the most utter rubbish that was ever honoured with the name of Portland Cement. During the last year or two, however, he has had occasion to test and examine samples of cement more recently produced in that neighbourhood, and the results show that, with proper care, a Portland Cement can be produced equal, if not superior, to the Thames and Medway brands. The following analyses, taken from our testing books of 1887 and 1901, may be given as examples of the Cambridgeshire marls ; it will be seen that they approximate very nearly to the constituents of raw Portland Cement slurry, and only require proper blending, or a very small addition of chalk, to bring

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them up to the 76 per cent. of carbonate of lime usually present in an ordinary slurry or compo :—

MARLS.

	No. 1.	No. 2.
Loss at 212° . . .	1·20	1·25
Silica	17·25	12·96
Alumina and iron oxide .	7·25	7·35
Carbonate of lime . .	73·92	76·66
„ magnesia .	trace	1·45
Alkalies and loss . .	·45	·33
	100·07	100·00

A source of raw material which has lately been utilised for cement-making purposes, is the lime-waste from alkali and similar works. The great obstacle which has hitherto prevented this material being utilised for that purpose, is the considerable amount of sulphide usually contained in it —sufficient, in fact, to render the cement absolutely dangerous and useless. A process has lately been patented by which nearly all the sulphur is recovered from the waste, rendering it sufficiently pure for cement-making purposes. The author had occasion recently to visit an alkali works where this waste, by mixture with a local clay, was successfully used for the manufacture of a high class Portland Cement. The waste being in an extremely fine state of division, it was found impossible to mix it with the clay by the continuous process of washing ordinarily in use with chalk and clay, as the waste simply passed out of the mill as fast as it was fed in. An intermittent process was therefore adopted, each mill-full being thoroughly mixed and tested as to the accuracy of the proportions before being conveyed to the drying floors. The waste being in such a fine state of division, one frequent cause of un-

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satisfactory results with ordinary chalk—viz. the presence of small unreduced lumps of chalk in the slurry—was eliminated; and, moreover, as it contained a considerable amount of carbon, also in a fine state of division, the fuel required for calcination was considerably less than that used with ordinary materials. Particular attention was paid to the grinding of the calcined clinker, and thus a first class Portland Cement was produced. Below are given the analyses of the raw materials and of the resulting cement :—

ALKALI WASTE.

Water and organic matter	3·80
Carbonic acid	39·60
Silica	1·98
Alumina	1·41
Oxide of iron	1·38
Lime	48·29
Magnesia	1·51
Sulphuric acid	1·26
Potash	·35
Soda	·29
	99·87

CLAY.

Water and organic matter	4·85
Carbonic acid	7·65
Silica	48·31
Alumina	23·35
Oxide of iron	5·16
Lime	5·81
Magnesia	2·81
Sulphuric acid	1·53
Potash	·32
Soda	·23
	100·02

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CEMENT.

Water and carbonic acid . . .	1·40
Silica	19·55
Alumina	10·65
Oxide of iron	3·30
Lime	59·55
Magnesia	2·41
Sulphuric acid	2·08
Potash	·51
Soda	·37
	99·82

The raw materials hitherto mentioned are the principal ones from which Portland Cement is manufactured in England. In the Appendix is given the chemical composition of materials which are utilised to a greater or less extent for cement making in England and other parts of the world, and which may be of interest as showing that cement-making materials exist almost everywhere, although not always in sufficient quantity, or capable of sufficiently economical treatment, to be available commercially.

The foregoing materials, differing widely in their physical properties, naturally require different methods of treatment in the first operation of mechanical mixture; these methods of treatment may be classed under two principal heads, viz. the wet process, and the dry process. The wet process is adopted for all those materials which by treatment in a wash-mill, with a large excess of water, can be broken up and reduced to a perfectly homogeneous creamy mixture, technically termed slip or slurry. The chalks and clays of the London district and elsewhere, and also the soft marls of the Cambridgeshire district, are treated by this process. The dry process has to be adopted with those materials which are of too hard a nature to be treated in the wash-

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mill. It consists of first drying the raw materials if necessary, grinding them together or separately to a more or less impalpable powder, and in the latter case, afterwards mixing the powders thus produced in the desired proportions; the resulting mixture is then damped sufficiently to enable it to be pressed into bricks, which are again dried, before being loaded into the kilns for calcination. In both processes the method of treatment after calcination is the same, the clinker being drawn from the kilns, and reduced to a powder by any convenient comminuting machinery.

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CHAPTER III.

WET MILLS.

THE wet method of manufacture may be subdivided into two separate heads, viz. the "Wet Process," and the "Semi-Wet or Goreham Process." The latter is the later, and more extensively used at the present time, as it does away with the necessity of backs or settling tanks; the slurry, after leaving the mills, being pumped direct on to the drying floors or kiln drying chambers, thus effecting a considerable economy in labour.

The "Wet Process" consists of mixing the chalk and clay, or other materials which are capable of such treatment, in a wash-mill with a large excess of water, until they are broken up and reduced to a sufficient degree of fineness to rise with the water and overflow the outer edge or circumference of the mill. The outlets of the mill are provided with a fine gauze sieve, to prevent any particles passing through that are insufficiently reduced. The "slip" or "slurry," as the thin liquid thus produced is technically termed, is then raised by elevators to a sufficient height to enable it to run by gravitation to a series of large settling reservoirs or "backs," from four to six feet deep, where it is allowed to settle, and the supernatant clear water gradually drawn off, until the slurry becomes sufficiently solid to admit of its being conveyed by tram wagons or barrows to the drying floors. The period allowed for settling depends, of course, upon the back room

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at disposal, and the requirements of the works; where gradients are favourable, the slurry is sometimes allowed to flow by gravitation to the drying floors, the greater part of the excess of water having, of course, been first drawn off. It is preferable, however, where possible, to allow it to remain in the backs until it has attained about the consistency of soft butter, as it can then be readily cut out with a wetted shovel and easily spread on the drying floors. If allowed to remain in the backs until it has dried beyond this plastic condition, the author's experience is that it does not dry so quickly, as the floor is not everywhere in contact with and covered with the slurry, and therefore a good deal of the heat escapes unutilised. Of course, if placed on the floor in a liquid rather than a plastic condition, there will be more water to drive off, and a correspondingly longer time must be allowed for drying, to say nothing of the extra fuel required for that purpose.

A convenient method of drawing off the water from the backs is to arrange a special penstock, consisting of a vertical opening or slit, two or three inches wide, in the wall of the back, communicating with a drain to carry off the water. Slips of wood about an inch deep, fitting into grooves at the sides of the openings, are puddled into position, according as the back is filled, so as to make a water-tight joint, and as the slurry subsequently settles, these blocks are removed one by one as occasion requires, thus allowing the clear water to run off.

The wash-mill, a sectional elevation and plan of which are given in Fig. 1, consists of an annular pit, about fourteen feet in diameter, lined with brickwork, in and around which revolve a series of harrows, carrying a number of suitable tines or knives to break up the materials under treatment. These harrows are suspended by chains from a series of radial horizontal arms, properly stayed and braced, the whole

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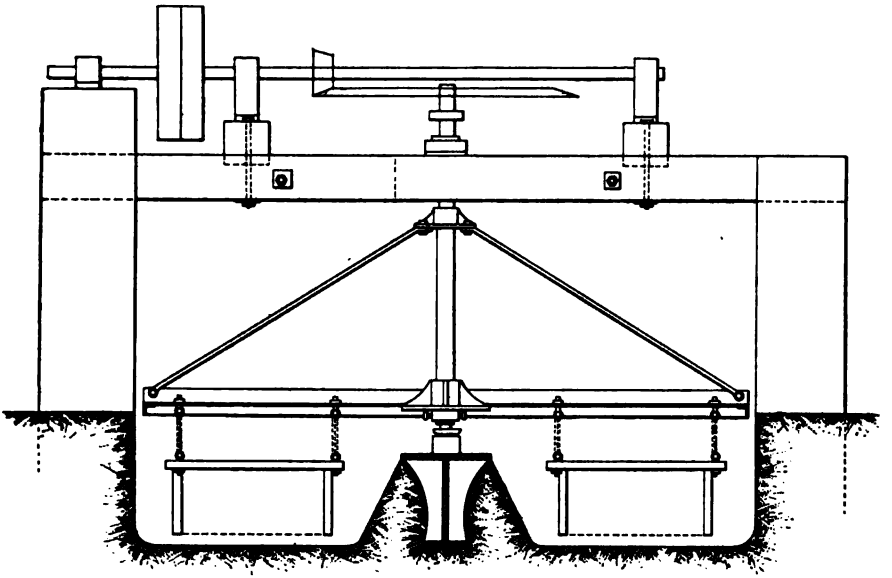
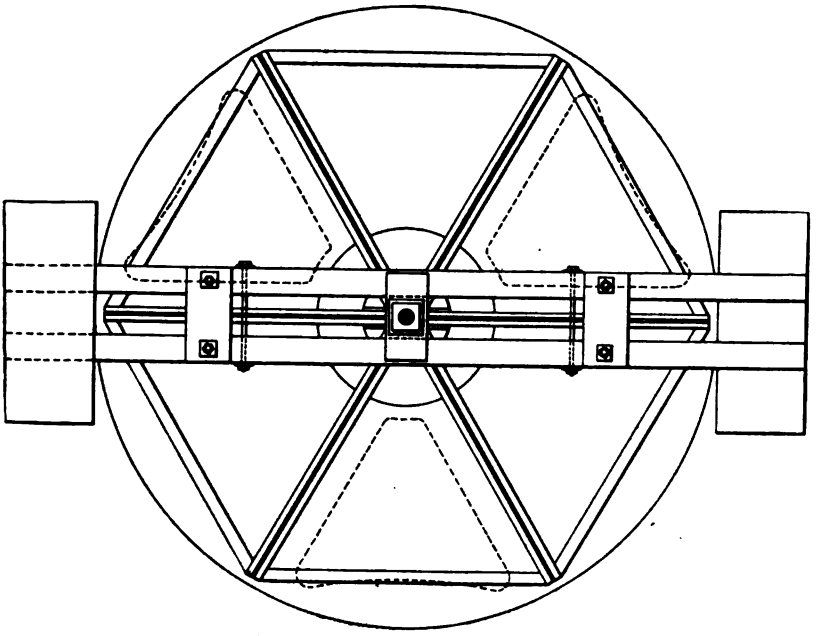


SECTIONAL ELEVATION.



PLAN

FIG. 1.

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mill being driven by a crown wheel at the top of the central vertical spindle. The illustration is reduced from a working drawing, and it will be noticed that only the two outside tines in each case are shown in full. The harrows are triangular in plan, as indicated by the dotted lines, and each one contains about twenty tines, which are so arranged that in their path round the mill every part of its area is swept by them. In order to further assist the breaking up of the chalk, spikes and jagged projections are sometimes inserted round the outer walls of the mill, so that when the chalk is violently dashed against them its reduction may be thereby assisted. This, however, is not a usual practice, and would only answer in the case of grey chalk, which contains no flints; the flints in an ordinary white chalk would soon render the projections valueless.

In using chalk and clay, the usual method is to feed the raw materials, by means of barrows, through a convenient tip hole at the side of the mill, a trustworthy man being placed in charge to see that the proper proportion of each material is used. It is unnecessary to add that this tip hole should be so arranged, in accordance with the direction in which the mill is revolving, that the materials will have to traverse the greater part of the circumference of the mill before coming to the outlet. This remark especially applies to the semi-wet process, for it is obvious that if the outlet grating is close to the tip hole, and the materials are dashed against it immediately on entering the mill, some of them, especially the softer clay, and probably some of the finer chalk, will pass through without being treated by the mill.

With most materials of this description it will be found convenient to arrange the barrows of such size that two barrows of chalk are required to one barrow of clay, both being weighed in, and so that, the chalk barrows being kept constant in weight and size, any alteration in the proportion

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of the raw materials used, may be effected by reducing or increasing the weight of clay used. In some cases it is found economical to first partially reduce the chalk, by running it through crushing rollers before feeding it into the mill, but the more usual method is to provide the wash-mill gang with sharp-pointed hammers or picks, with which to break the large pieces of chalk, so that no chalk is fed into the mill in larger pieces than three or four inches in diameter. Of course, immediately the materials are fed into the mill the larger pieces gravitate to the bottom, where they are gradually reduced by the action of the harrows until fine enough to pass out through the sieves at the opening provided for that purpose. The water necessary for the reduction of the materials is generally fed in at the centre of the mill, the supply pipe leading into a circular funnel arrangement fixed to the centre spindle, which revolves with the mill, and from which two pipes deliver just above the level of the harrows; this method ensures the water being more evenly distributed than if fed in from any fixed point on the outside.

Where the chalk or clay is at all sandy, it will be found a great advantage to provide a series of catch-pits, to intercept and separate the sand from the slurry as it passes from the wash-mill to the backs. These catch-pits may be of any convenient size, say about 4 feet by 2 feet by 3 feet deep, and the slurry should be allowed to pass quietly through them, or more correctly speaking, over them, for as soon as they become filled, the current passing from the wash-mill simply flows over them and deposits its heavy sandy matter in its passage. It will be found that they will require cleaning out occasionally, according to the quantity of sand present in the raw materials; the amount of sand in the pits can be easily determined by probing with a light wooden wand, the sand having a distinctly different solid

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sandy consistency as compared with the softer, almost oily nature of the slurry.

In working by the wet process the author found it advantageous to thoroughly "lute" and "drag" the backs periodically, so as to ensure the contents of each one being perfectly uniform, otherwise the lighter portions of the clay have a tendency to separate from the chalk during settlement. For luting, a long pole was used, having a flat piece of board about eighteen inches long by nine inches wide fixed at one end; with this instrument the luter walked along the wall of the back, and thoroughly stirred up the slurry for the first few yards from the outside. To enable the contents of the centre of the back to be mixed up, an instrument called a "drag" was used; this consisted of a rectangular piece of board, about 2′ 0″ × 1′ 0″, at the centre of either surface of which was an iron eyelet secured by a metal strap passing round the board; two ropes, each long enough to reach across the back, were attached to these eyelets, so that two men standing on opposite walls of the back could pull the drag to and fro flatwise between them, and, by taking a fresh position after each haul, the whole of the contents were rendered fairly uniform. A mistake that is sometimes made is to allow the slurry all to run in at one corner of the back instead of at different points. The difference in the gravity of the materials tends to cause them to separate more or less as the slip flows forward to the further parts of the back, and if the mixture enters at one point only, it will generally be found that the composition of the slurry at the more remote end of the back differs materially from that near the shoot. A convenient practice is to have three or four shoots at different places, so that the point of entry can be changed every day or every other day. By this method, and by having the back which is being filled dragged and luted

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an hour each day, a uniform composition of the slurry is ensured at trifling extra cost.

The chief point of difference between the "Wet Process" and the "Semi-Wet Process," is, that in the former the whole of the work is done by the wash-mill itself, with the aid of a large excess of water, and after leaving that mill, the raw materials are, or ought to be, in a perfect state of mechanical amalgamation; whereas, in the latter process much less water is used and the wash-mill only partially completes the work, the final reduction and mixing being accomplished by means of millstones or other convenient grinding machinery. Although the latter process effects a considerable saving of labour over the older "back" system, the author, having had experience of both, must confess to a sneaking fondness for the older method, so far as regularity and reliability are concerned, as, by systematically testing each day's washings and periodically checking the contents of the backs, any little excess of chalk or clay in one day's work can be adjusted the next, whereas with the semi-wet process, the slurry goes direct from the wash-mill to the kilns, and, whether it is correct or otherwise, there is no opportunity of correcting or amending errors in the mixture of the raw materials. Although with the present facilities of testing slurry at frequent intervals during the day, the possibilities of error are very largely reduced, only those who have had charge of cement works where the raw materials vary to any considerable extent, can appreciate the difficulty of always keeping the proportions exactly right. In one instance, it was found that a divergence of less than 1 per cent. below or above the proper percentage of carbonate of lime, meant in the one case a considerably weakened cement, and in the other an over-limed one, or at all events a cement that would be unsafe to use without

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thorough aeration and maturing. The author is therefore inclined to the opinion, that where very variable raw materials have to be dealt with, and where a few pence per ton in the cost of production is not of such paramount importance as regular and consistent quality of the product, the use of backs or of very large mixing tanks will be found advantageous. The semi-wet system, although it effects a considerable economy in labour, rarely gives such good results, either in quantity or quality, as the older wet system.

By the semi-wet process a much less quantity of water is used in the wash-mill, hence the derivation of the term "semi-wet," only sufficient being added to render the mixture sufficiently fluid to be readily pumped on to the drying floor or kiln drying chamber; the slurry in this process generally contains from 40 to 45 per cent. of water, which means about 10 or 15 per cent. of added water, according to the amount contained in the raw materials. The wash-mill used for this process is practically identical in construction with that used for the wet process, except that it has to be somewhat strengthened in its details, inasmuch as the mixture being of a much thicker consistency, the friction of the harrows passing through it is proportionately greater. Instead of the fine wire gauze at the outlets of the mill, as with the wet process, a stout iron grating is used, the individual bars of which are wedge-shaped in section, as shown in Fig. 2, the broader end of the wedge facing inwards; these bars are usually placed about $\frac{3}{8}$ inch apart, so that when the materials are sufficiently reduced to pass this grating they leave the wash-mill to be further treated by the millstones. On leaving the wash-mill the rough slip or slurry passes into the elevator sump, whence it is elevated by means of a strap elevator or other convenient method to the small feeding tank placed over the stones. This elevator ordinarily consists of a

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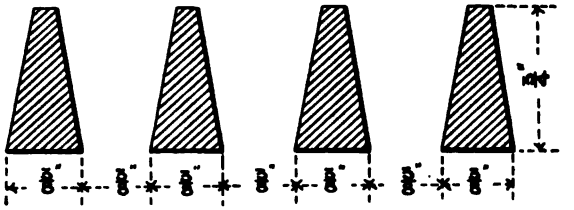
rubber composite belt, about one foot broad, running on flanged pulleys top and bottom, with buckets bolted to it of such size and at such intervals, that the amount of slurry passing through the mill can be readily dealt with. Like all elevators of this class, it is, of course, driven from the top pulley, and for work of this sort it is essential that the bucket belt should be kept fairly tight so as to prevent slipping, as far as possible, should its inner surface come into contact with the greasy slurry. A very good arrangement for effecting this object, which from personal experience answers very well, is to arrange the bearing of the lower pulley on a sort of rectangular frame which is



SECTION OF GRATING.

FIG. 2.

hinged at one end and weighted at the other, so that any slight slackness of the belt, due to stretching or other cause, is thereby compensated, and the elevator always maintained at one degree of tension. Although belt elevators have now come into general use for this purpose, wheel elevators of the type shown in Fig. 3 are sometimes used for slurry elevation. As will be seen from the illustration, which is reduced from a working drawing, it consists of a large skeleton wheel with buckets fixed on its outer circumference, and it must of course be of sufficient diameter to elevate the slurry to the desired height. There is this to be said in favour of the wheel elevator, that when it is

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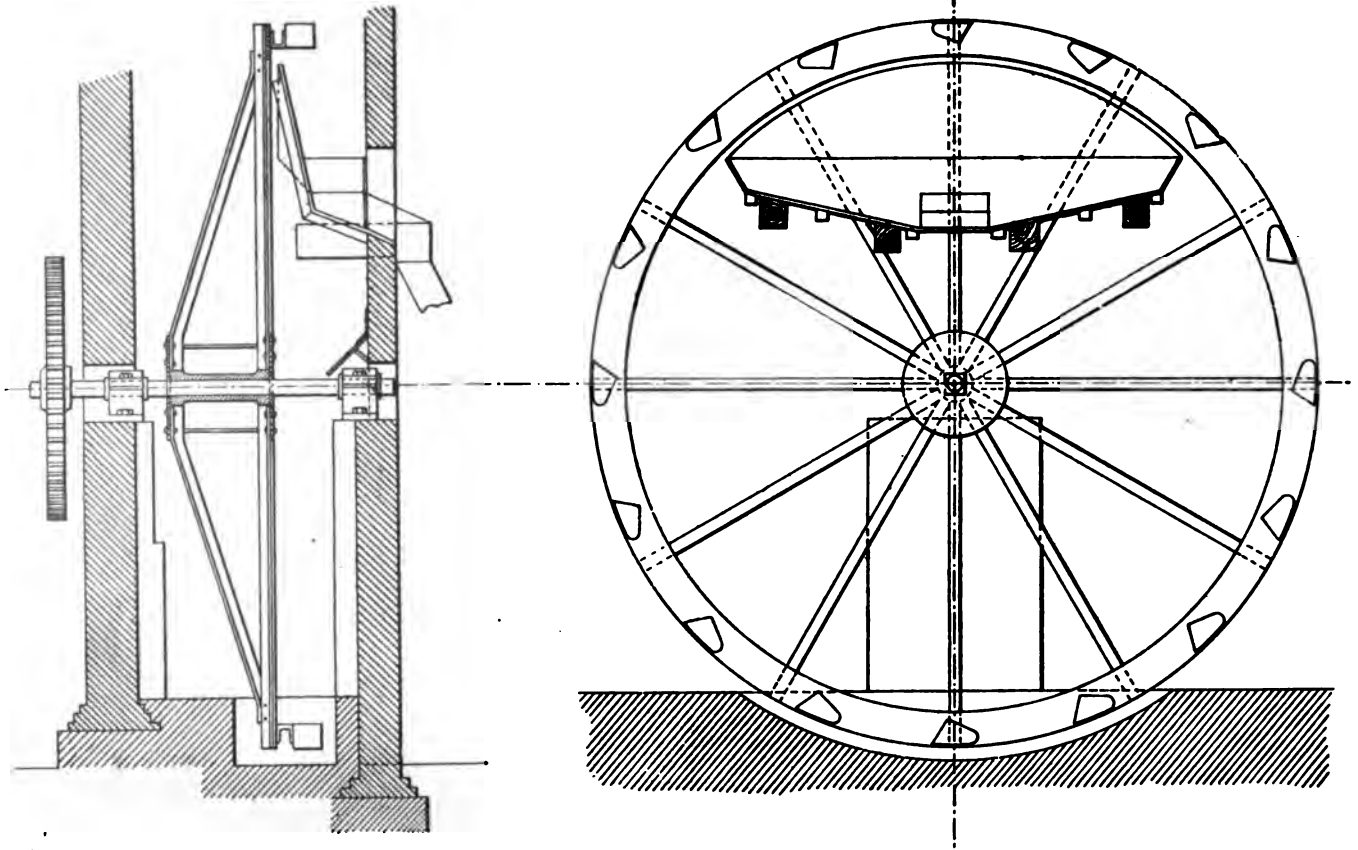

FIG. 3.

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once erected, it will run for a long time with practically no attention, whereas the wear and tear on a bucket belt is considerable, and a firm of manufacturers recently assured the author that they had quite lately abandoned belt elevators in favour of the wheel type.

With the white chalks, where flints are abundant, and often embedded in the centre of the mass, it is impossible, even by the most careful picking, to prevent a certain amount of flint passing into the wash-mill, and the friction of these flints causes the harrow tines or knives to wear away very rapidly. The usual form of harrow tine is square in section, with a shoulder and thread formed at the upper end to enable it to be passed through the opening provided in the harrow frame and firmly fixed thereto by means of a nut. Where these tines or knives wear very fast on account of flints, a modification is sometimes adopted, the tines being made of flat bar iron, rectangular in section, fixed by means of a set screw to a specially designed harrow frame, and projecting through the top; as the bottom of the tine wears, the working end can be lengthened by loosening the set screw and lowering it through the harrow frame to the desired depth. A further modification of the same idea, is to adjust the height of the tine by simply passing a ring or pin through it, to prevent it falling too far through the frame, and holes being made in the tine at suitable intervals, it can be lowered by simply shifting the pin or ring to the hole next above it.

In cases where a hard chalk has to be used which is more than usually difficult of reduction, the wash-mill process is sometimes divided into stages, the chalk alone being first dealt with and reduced before the clay is added. It is usual in such cases to first pass the chalk through crushing rollers, which partially reduce it, whence it passes to wash-mill No. 1; here water is added, and by means of heavy

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harrows of special design, it is broken up fine enough to pass a coarse grating into mill No. 2. In this mill the clay is added, and the slurry passes out into mill No. 3 for a final mixing and reduction, after which it is passed through wet stones, to ensure the thorough reduction of the chalk and a complete amalgamation with the clay.

With flinty chalk, it is also found necessary to periodically run the mill empty, or "wash down" as it is called, in order to remove the flints which accumulate at the bottom of the mill; this is accomplished by stopping the supply of chalk and clay, and continuing for a while the supply of water, so that in a few minutes all the reducible material has passed out, and nothing is left in the mill but the flints, and perhaps a few very hard pieces of chalk. Generally speaking, it is undesirable to allow this thin slip and excess of water to pass to the kilns in the ordinary way, a more convenient method being to pump it into a small back or reservoir specially constructed for that purpose, and utilise the slurry thus produced for daubing kilns, and odd jobs of a similar nature. In addition to the large excess of water, the wash-down slurry generally contains a considerable excess of chalk; owing to the clay being the more easily reduced, as soon as the supplies are stopped it rapidly passes out of the mill, and the remaining slurry, if not pure chalk, at all events contains a great deal too much of that material. To avoid this excess of chalk, the author always adopted the plan of adding one or two barrows of clay, according to requirements, during the wash-down process, so that, with the exception of an excess of water, there was not much amiss with the resulting slurry.

The Michele wash-mill, of which an illustration is given in Fig. 4, is used in some works. Its essential principle is that it completes the grinding and amalgama-

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tion of the raw materials in one operation. The slurry is made to leave the mill by overflowing between the grinding

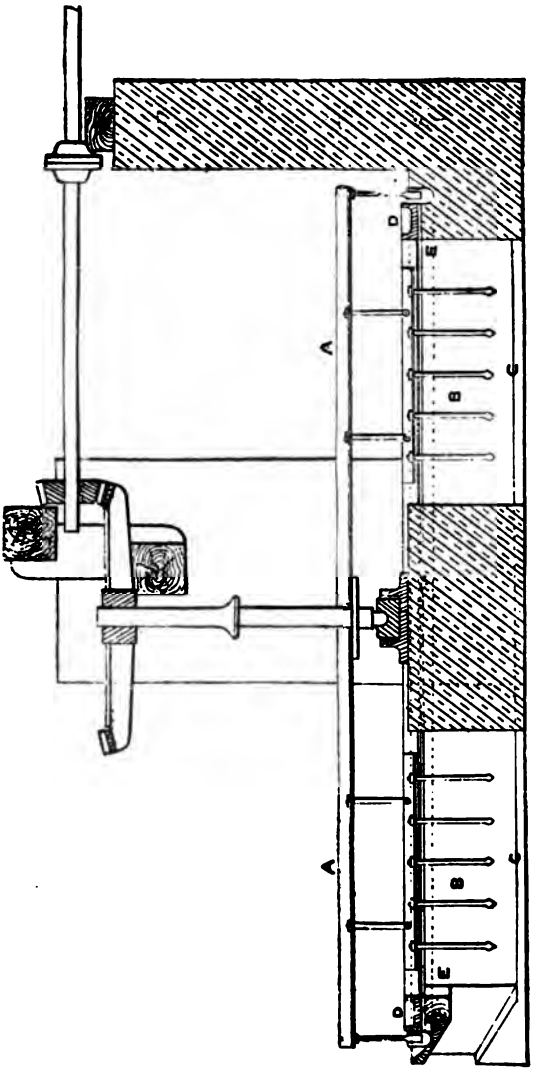

FIG. 4.

surfaces of a broad rim of iron D, forming part of and revolving with the mill, and a corresponding flat rim fixed on

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the outer wall of the mill; the particles are thus subjected to a grinding action and reduced to a fine state of division. By this means both slurry elevators and wet stones are dispensed with, and the slurry as it leaves the mill can be pumped directly to the drying floor or kiln chamber. Where a grey chalk is used which contains no flints this mill gives very satisfactory results; but, from personal observation, the slurry produced from white flinty chalk leaves a good deal to be desired. As with all machinery for the final reduction of slurry, the flints contained in the white chalks are a considerable source of trouble; not only do they tend to lift the grinding surface, and thus allow small particles of unreduced chalk to escape, but also cause considerable wear and tear of those grinding surfaces or rims.

The millstones generally used for the final reduction and amalgamation of the slurry are the ordinary French burrs of the usual bedstone and runner type. The most general size is 4 feet 6 inches in diameter, and they are almost exactly identical in gearing and general details with the stones used for grinding the cement clinker, of which an illustration is given in Fig. 27, p. 130. The work they have to perform being considerably lighter, the gearing does not require to be quite so heavy, and the method of feeding of course has also to be modified. The usual method of feeding the wet stones is to allow the rough slurry to run from the small feeding tank or reservoir above, where it is deposited by the elevator, through a wooden shoot or trough into the eye of the stone, a separate shoot with a suitable cut-off arrangement being provided for each pair of stones. To prevent the slurry splashing off the crossbar out at the eye of the stone, and thus passing to the pumps without proper reduction, a circular cap or disc is fitted over the eye, which encloses it altogether with the exception of a hole about 6 inches in diameter through which the slurry is fed. As

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with cement stones, the wet stones are generally arranged on a line shaft, in which case, instead of the wooden trough arrangement above mentioned, a neater method of arranging the feed is to distribute the slurry from the service tank through an ordinary 6-inch cast-iron slurry pipe running along at the back of the stones, with a T-joint and short length fitted with a cut-off for each pair of stones.

It is hardly necessary to add that, in order to obtain good results with the wet stones, they must be accurately balanced so as to run true, and also be properly dressed. The dress of millstones is a matter upon which all practical men differ, so that it is hardly possible to lay down any hard and fast rule on that point. The dress adopted by the author for a pair of stones of 4 feet 6 inches diameter, and which he found to give very good results, was as follows.

RUNNER.—*Face*, or true horizontal grinding surface, ten inches wide, properly staffed down.

Throat or swallow, commencing three inches above face and gradually diminishing towards same.

Cracks or furrows, about three inches apart and extending from throat to about five inches from edge of stone, viz. three inches beyond commencement of face.

BEDSTONE.—Same face and furrows as runner. Breast to be kept down half an inch below face.

It was found that stones dressed according to the above method did not require taking up more than once a month, and produced a very good slurry, but this of course would depend entirely upon the nature of the materials to be treated.

In order to practically avoid the necessity of dressing wet stones, Messrs. Addison, Potter and Son, of Newcastle, have patented a system of building them up, by which the eye or throat is composed of burrs in the ordinary way, but

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the grinding surface or face is made up of pieces of rock emery, set in a specially prepared metallic composition. By this means they claim that the face always keeps sharp, and only the throat requires occasional dressing. The author has not had personal experience of these especially prepared stones, though certain well known manufacturers in the north of England testify to their efficiency.

The tube mill, used for the final reduction of the cement clinker (see Fig. 43), has been adopted in some instances instead of millstones for completing the grinding of the slurry. Although its efficiency leaves nothing to be desired, the author understands that it compares rather unfavourably with other methods as regards economy.

The pipes used for conveying the slurry from the pumps to the drying floors or kiln drying chambers, are usually of cast iron, of six inches internal diameter, with flanged joints. It is perhaps unnecessary to mention that they should be covered with a protective coating of straw or similar material to prevent injury from frost, through the freezing and consequent expansion of the slurry contained in them. The pipe line being necessarily carried over the top of the kilns, is consequently often in a rather exposed situation, and instances have occurred during severe winters of considerable damage and inconvenience through the neglect of this simple precaution. In some works a half-inch wrought-iron pipe is placed inside the slurry pipes, and a jet of steam passed through it when necessary; this has been found very effective in preventing the slurry from freezing. The form of outlet from these pipes, though perhaps a minor detail, is one which will fully pay for proper consideration. A very convenient form is that shown in Fig. 5, commonly known as the "treacle-pot" outlet, being of the same design as that used for cutting off the flow of such viscous fluids. The illustration is reduced

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from a working drawing, and shows the outlet in plan as seen from beneath, and in elevation. The cut-off disc, part of which is elongated into a projecting handle, swings on the bolt at the right, so that the flow can be wholly or partially cut off as required. Anyone who has experienced the squirting power of slurry under pressure, by trying to screw on an ordinary plate cover while the pumps have

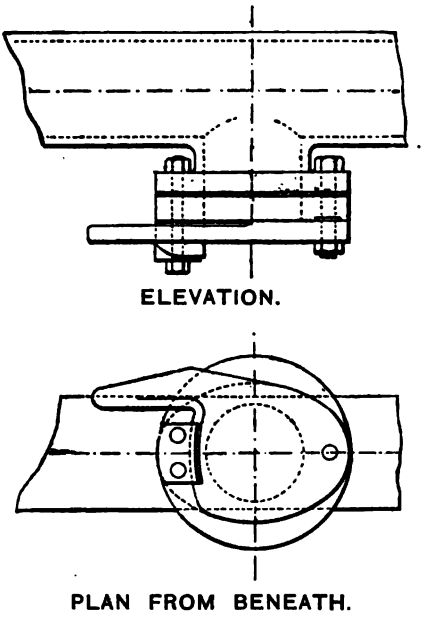

FIG. 5.

been working to force the slurry to a kiln further on, will fully appreciate the utility and convenience of the "treacle-pot" outlet.

The pumps generally used for forcing the slurry through the distributing pipes are of the usual three-throw type, shown in Fig. 6, with heavy plungers of about six or eight inches diameter, according to the work which they have to

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perform. An air chamber is attached to the delivery pipe to equalise the pressure, and on the top of this air chamber is fixed a Bourdon pressure gauge. By this means, the man

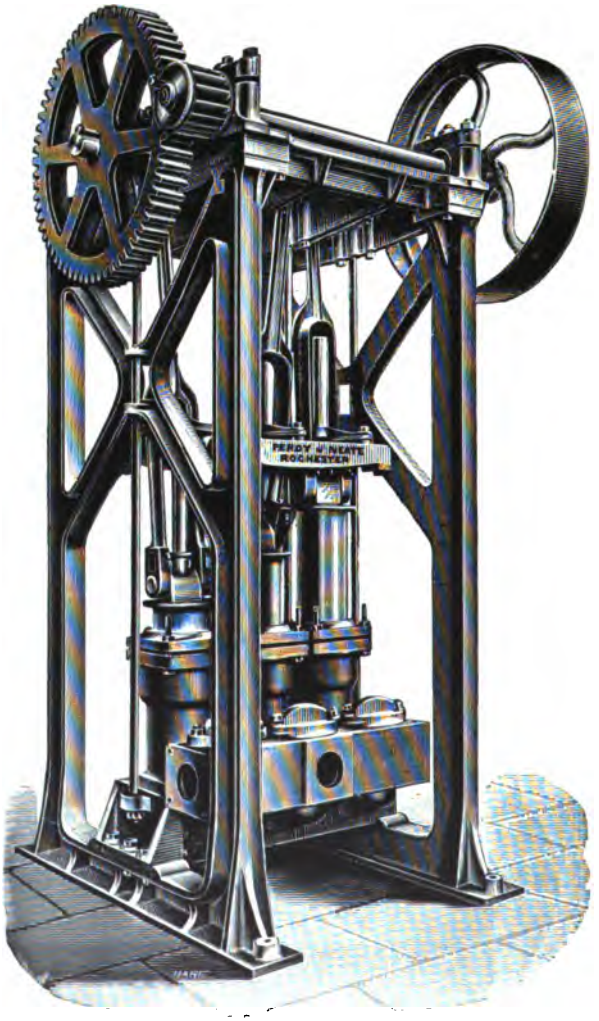

FIG. 6.

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in charge can always see what pressure he is putting upon the pipes, and, knowing what the pressure should be to a certain distance, he can to some extent thereby regulate the fluidity of the slurry. To prevent any chance of accident or damage to the pipes or gearing from over-pressure, a weighted safety valve is fitted to the delivery pipe, which allows the slurry to blow off back into the sump when the pressure exceeds a certain limit. These pumps are driven by fast and loose pulleys, and the crank driving each pump is arranged at a different angle on the shaft; by this means each pump does its work at a different period of the revolution of the shaft, thus equalising the pressure and maintaining a steady stream of slurry. If a certain pump is not doing its work properly, the pressure on the gauge will naturally drop suddenly during the stroke of that pump, and an examination of the gauge will, therefore, indicate if each one is doing its fair share of work.

Where the chalk supply is at convenient distance, arrangements are sometimes made to wash the chalk at the quarry, and pump it to the works in a fluid condition. In one instance where this is done, the chalk is washed with a considerable excess of water, practically the same as when used for the wet process, and is then pumped to the works to a series of settling backs, where the greater part of the water is allowed to drain off. It is then conveyed in wagons to the wash-mill, where the clay is added, and after leaving this wash-mill passes through a second one, to ensure complete mixture with the clay before going to the slurry pumps for distribution to the kilns. The proportions of chalk and clay are based on the weight of dry chalk, and as the water contained in the washed chalk necessarily varies a good deal, the exact amount is carefully estimated every day and the proportions calculated therefrom. By this method, wet stones

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may be dispensed with, as the chalk is thoroughly reduced in the quarry wash-mill before being pumped to the works, while the soft nature of the clay enables it to be thoroughly reduced and amalgamated with the chalk by passing through the two consecutive wash-mills at the works. If the chalk contains any appreciable quantity of sandy gritty matter or fine flints, such will be found to settle in a fairly well-defined heap under the shoots where the fluid chalk enters the backs. This sediment cannot, of course, be used for cement-making purposes under such conditions, and it is therefore carefully avoided by the wash-mill gang, and removed when the back is emptied.

The most important item of the semi-wet process is that the chalk should be thoroughly reduced and the materials thoroughly amalgamated. Where a flinty chalk is used, little pieces of flint, in passing through the wet stones, are so difficult of reduction that they raise the edge of the stones and cause them, in the miller's parlance, "to throw grit," i.e. allow coarse particles of chalk to escape. There is no doubt that, in this particular, the semi-wet process, as at present carried out, is inferior to the wet process, as the mechanical mixture is rarely so perfect as by the older method. The clay being of a readily reducible nature, will generally amalgamate fairly easily, the chief difficulty lying with the chalk. Samples should, therefore, be taken periodically from the shoots leading to the pumps, to ascertain if the reduction is efficiently accomplished. A rough opinion can be formed by the feel of the slurry between the thumb and finger; if unreduced particles of chalk are present to any appreciable extent, it will have a rough gritty feeling instead of the smooth creamy consistency of a perfectly washed slurry. The best method of testing its fineness of reduction is to wash a measured quantity, say ten fluid ounces, through a sieve of 50 holes per

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lineal inch, and also through one of 180 holes, and to measure any residue that may be left in a graduated measuring vessel. The residue on the former sieve should not exceed ½ per cent., and on the latter 5 per cent. On the excellence of this mechanical mixture more depends than is generally recognised, as if the coarse particles of chalk in the slurry exist to any great extent, it will be impossible for the silica and alumina of the clay to combine properly with them, or, so to speak, for the silica and alumina to soak up the lime during the process of calcination. If the mixture is imperfect, the combination between the lime, silica and alumina will also be imperfect, and an imperfect and greatly weakened cement is the result. Further than this, the more complete the mechanical mixture, the greater the quantity of chalk that can be used with safety, and, *cæteris paribus*, the stronger the cement obtained; and, what is still more important, it will generally be found that an imperfectly or badly washed slurry will tend to produce a weak and blowy cement, owing to the imperfect combination of the lime in the process of calcination. A marked illustration of the above fact, viz. that the better the mixture the greater the amount of chalk that may be used with safety, occurred a short time back, at a cement factory where for a time both wet and semi-wet processes were in operation; the same materials were used in each case, and it was always found that, owing to the more perfect mixture obtainable with the wet process, one or one and a half per cent. more carbonate of lime could be used with safety than with the semi-wet process. From personal observation at the various cement works in the London district, there is no doubt that, in this particular, there is room for great improvement in the English practice, and a little money expended on the perfection of the mechanical reduction of the raw materials, would be amply repaid by

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an improved manufacture, to say nothing of less liability of danger if the slurry is rather fully limed.

As an illustration of the foregoing remarks, full-sized photographs of three samples of slurry are reproduced in Figs. 7, 8 and 9, showing different degrees of perfection of the mechanical mixture ; they may be classed as examples of badly washed and well washed slurry, and the ideal mixture. The first two are samples of the ordinary wash-

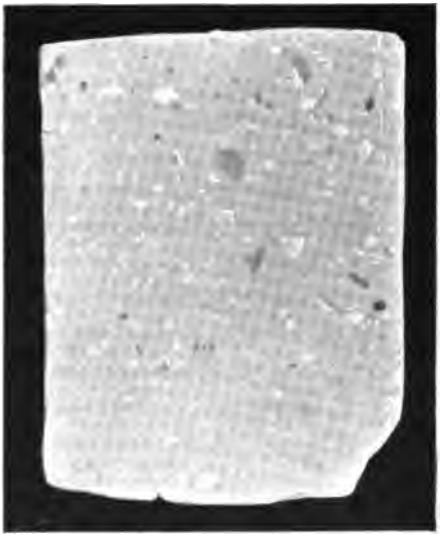

FIG. 7.

ing of two large works in the London district, while the third is what the second firm have been able to produce, in limited quantities, by special methods, and which they eventually intend to obtain with the whole of their manufacture. In No. 7 it will be seen that the pieces of unreduced chalk range as large as $\frac{1}{8}$ inch in diameter ; and pieces of flint of about the same size, which are doubtless responsible for the imperfect grinding, are plainly visible as black angular

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fragments in various parts of the sample. In No. 8 there are no particles of chalk much larger than the point of a pin ; while in No. 9 the mixture is so nearly homogeneous that the presence of minute particles of unreduced chalk is only indicated by the streaks produced by the knife in planing off a level surface for the purpose of obtaining a photograph.

The bad effects of faulty washing, i.e. coarse particles of chalk in the slurry, may be obviated to a certain extent by

FIG. 8.

using more fuel in calcination, as the higher the temperature the more readily the coarser particles combine, but by this means the resulting cement is materially weakened, as in obtaining a sufficient temperature to cause these coarser particles to combine, the other parts of the slurry are overburned, or calcined beyond that point of incipient vitrification which has been found to produce the best cement, to say nothing of the cost of the extra fuel consumed.

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The author was lately assured by a member of a large firm of manufacturers, who had recently put down special plant to improve the reduction of the chalk and the intimate mixture of the raw materials, that they had found such a course to be economical, as the more thoroughly washed, or rather the more finely ground slurry thus produced, took considerably less fuel for calcination than before. It needs very little comprehension to understand that, within certain

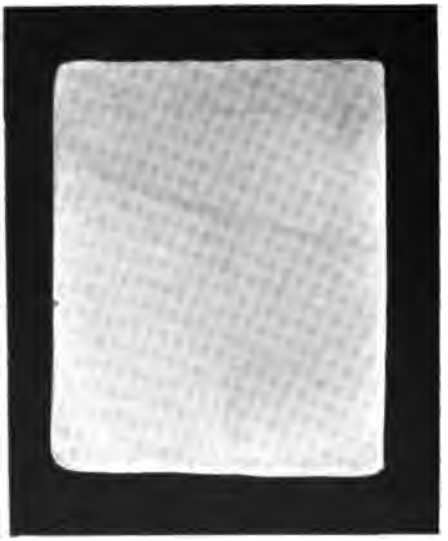

FIG. 9.

limits, the more complete and intimate the mechanical mixture, the less heat will be required to bring about the proper chemical combination.

Some manufacturers, in order to further perfect the mixture, and render the composition of the slurry constant, make use of auxiliary mixing mills, into which the slurry is run after it leaves the wet stones. These mills or mixers consist of deep circular pits, about 15 feet in diameter and

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6 or 8 feet deep, according to the quantity of slurry to be dealt with, in and around which revolve slowly a series of long vertical arms or stirrers suspended from and carried round by a horizontal radiating beam, which is driven from a centre spindle very much like a wash-mill, in fact the whole mixer is a modification of the ordinary wash-mill. Two or more of these mills are used in accordance with the quantity of slurry to be dealt with, and in addition to perfecting the mixture they are sometimes used intermittently, as at Boulogne, in order to check the proportion of carbonate of lime before the slurry is pumped to the kilns. For this latter purpose one mill is nearly filled and a sample taken for testing purposes, the slurry meanwhile being turned into the second mill while the estimation is being made. If the mixture is correct, it is allowed to go forward to the kilns; if not, it is adjusted by adding clay or chalk according to requirements. The author recently had an opportunity of inspecting an installation of very large mixers of this type, for use with a rotary kiln plant, in which it is imperative that the proportions of clay and chalk should vary within very narrow limits. These mixers, of which there were three, each had a capacity equivalent to 500 tons of cement, and the contents were kept in continual motion by slowly revolving vertical stirrers attached to a still more slowly moving horizontal arm, reaching from the centre to the outside of the tank.

The more perfect mechanical combination, or rather the raw materials being more similar in their chemical composition, is doubtless one reason why cement made from the Lias districts of Rugby will bear a higher percentage of lime than those made from chalk and clay. As will be seen from the analyses on page 22, the Lias stone contains a considerable amount of silica and alumina, and the shale likewise contains a considerable amount of

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carbonate of lime, and therefore any unreduced particle of either stone or shale would not be so totally dissimilar from the composition of the properly mixed materials, as would be the case with a chalk containing say 99 per cent. of carbonate of lime, and a clay containing practically none; hence the result of an imperfect reduction of the former materials would not be so likely to lead to disastrous results as with the latter.

When a grey chalk which contains no flints is used, the wet stones are sometimes dispensed with altogether, and the work of reduction carried out entirely by the wash-mill. According to the process patented by the late Mr. W. G. Margetts, which is in use at the West Kent Cement Works, instead of the outlet from the wash-mill being fitted with a grating with $\frac{3}{8}$-inch openings, a perforated iron plate is used having $\frac{3}{8}$-inch circular holes, and the slurry, after passing through this plate, is elevated to the wet mill in the usual way. Instead, however, of being treated by wet stones, it is passed through vertical revolving sieves of the section shown in Fig. 10. The framework of this sieve is angular or polygonal in horizontal section, and is covered with brass wire gauze of about 20 meshes per lineal inch. As will be seen by the illustration, it is so arranged that the slurry is fed in on to a concave plate fixed to the spindle, whence it is projected on to the sieve. The material passes by centrifugal force up the slope of the cone towards the outer edge of the sieve, and by that means the sufficiently reduced particles pass through, and are led to the pumps in the usual way, while those particles which will not pass the sieve, fly out over its outer edge and are led by a convenient spout back to the wash-mill to be further reduced. The main advantage of this process is that the power required to drive the sieves is infinitesimal as compared with that required for the wet stones, and the finished slurry all having to pass

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through the sieves, the proper and even reduction of the chalk is thereby assured. From recent personal inspection, the slurry thus produced, is quite equal if not superior to that usually produced by the wet stones. The use of a perforated iron plate at the outlet from the wash-mill, in place of the usual grating, naturally tends to keep the materials longer in the mill, and thus causes them to be more thoroughly reduced in the first instance. Of course, this method could not be used with a flinty chalk, as the small pieces of flint would very quickly cut holes in the sieves

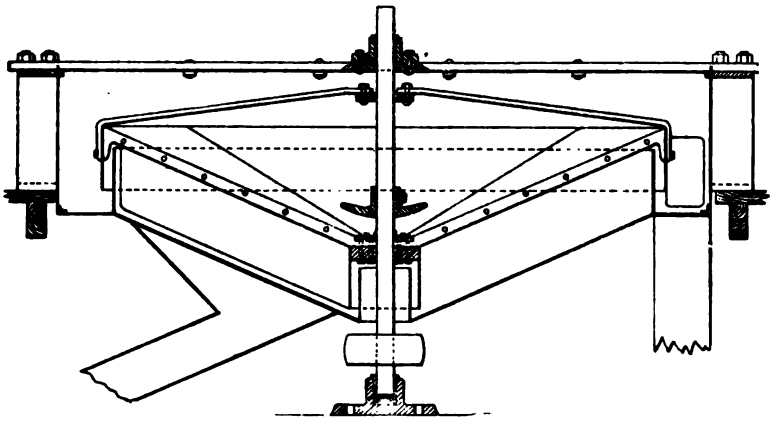

FIG. 10.

and render them worse than useless. It may be mentioned here that this patent anticipated by a few weeks a similar one taken out by the late Henry Faija, in February 1885, for an exactly similar purpose and accomplished in practically the same manner. It was exhibited by him at the Inventions Exhibitions of the same year, but, probably owing to the priority of Mr. Margetts' patent, was dropped shortly afterwards. The essential difference, however, between the two patents was that the Faija sieve was vertical and cylindrical, whereas the Margetts patent is conical and

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angular. In the latter case the coarse particles work to the edge by centrifugal force, whereas in the former they were made to drop towards the bottom by a tappet arrangement on the sieve itself.

The first point of importance in the manufacture of Portland Cement, is that the raw materials should be mixed in their correct proportions, as, if incorrect proportions are used in the first instance, it is impossible to remedy the error afterwards. This applies more particularly to the semi-wet process, where the slurry is pumped direct from the wet mills to the kiln drying floors, and no correction of errors can then be made. The original method of checking the correctness of the proportions, was to take a sample of slurry as it came from the wash-mill, say sufficient to produce a bushel of clinker, dry it, and calcine it in a small sample kiln specially kept for that purpose, grind the clinker separately, and test the cement thus produced in the usual way. Where backs were used, it was the custom to take an average sample from each back after three or four days' washing, and correct the mixture in that particular back by adding more or less chalk in the subsequent washing, according as the samples thus tested showed the contents of the backs to contain an insufficiency or an excess of that material. This method answered fairly well with backs, but with the introduction of the semi-wet process, it was scarcely so satisfactory, as the correctness or otherwise of the washing could not be ascertained till at least two days after the sample was taken, and in the meantime the proportions might have become hopelessly wrong. Although the cement produced from such a small sample kiln gives a very good general indication as to what the cement will be when produced in larger bulk, it differs widely in many respects from the cement produced from clinker calcined in large masses in the ordi-

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nary way. The setting is generally considerably quicker, and probably owing to the calcination being more regular, a sample burnt in a small sample kiln will bear considerably more carbonate of lime than one burnt in a large kiln in the ordinary way. It therefore follows that a cement produced from a sample kiln showing very slight signs of "blow," will generally mean serious "blow" when the same slurry is calcined in a full sized kiln in the ordinary course of manufacture.

The most convenient method of checking the proportions of raw materials during working, is to ascertain the percentage of carbonate of lime in the slurry or compo, which is generally accomplished by estimating the percentage of carbonic acid, and calculating therefrom the carbonate of lime. There are several well-known methods of estimating the carbonic acid gas in any given substance: the most convenient, perhaps, for the cement manufacturer's purpose is the volumetric method, which readily enables the volume of gas to be determined, and, by the use of tables, the percentage of carbonate of lime in the slurry can be estimated in a very few moments.

The first apparatus for this purpose that was used to any extent, was that devised by Dr. Scheibler, shown in Fig. 11. The gas is generated in the bottle A, and passes into the india-rubber bladder K in the bottle B. The consequent displacement of the air causes the water in the graduated tube C to fall accordingly, and thus the amount of gas generated is measured. Supposing the apparatus to be connected up, as shown, and bottle E full of water, the method of working is as follows: Open the nipper tap P, and blow through V, till the tubes C and D are filled with water a little above zero point. Then close P, and by slightly opening it again, the water is allowed to run back into E until it is exactly at the zero point. The stopper of

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A being removed, the water in filling C drives the air back into B and compresses the bladder K, which should be almost completely collapsed before each experiment so

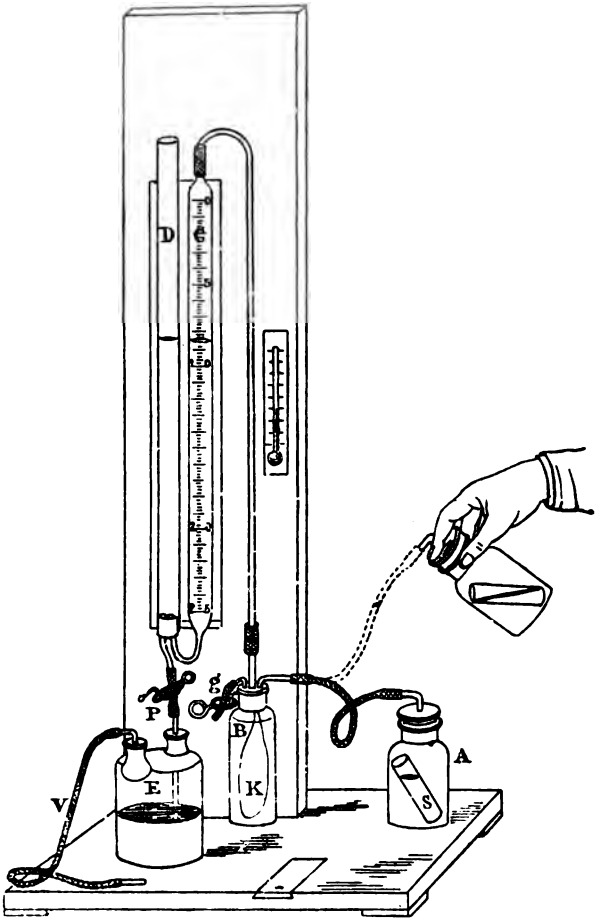

FIG. 11.

that there may be no risk of the gas subsequently generated being in any way compressed within it. On the other hand, if the bladder is empty before the water in

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the tubes reaches zero, the air in B would be compressed, and the water in the graduated tube C would not reach the zero mark, in which case the tap *g* should be slightly opened to allow of the escape of the excess of air. Of course, once the apparatus has been adjusted the bladder will empty itself after each operation.

Take out the gutta-percha acid tube S, and place a weighed quantity of dried and finely powdered slurry into the bottle A, taking care that the inside of the bottle is carefully wiped dry before each operation. Fill the tube S with 10 c.c. of hydrochloric acid of 1·12 specific gravity, wipe off any acid that may have escaped down the sides, and place it carefully in the bottle A, taking care that none of the acid is spilled during the operation. On closing bottle A with a well greased stopper, the water in C will sink slightly, owing to the compression of the air. On opening the tap *g* for a second or so, the pressure is removed and the water again rises to zero point. Take the bottle A with the right hand, holding it by the neck so as to avoid warming as much as possible, and slightly incline it so that the acid runs out of the tube on to the slurry. The gas will immediately be given off with considerable effervescence, and cause the water to fall in tube C and rise in tube D. By carefully opening tap P during the operation, the water in the two tubes should be kept as near the same level as possible. Tilt bottle A by degrees so that all the acid runs out of the tube, and when the effervescence has practically ceased, thoroughly shake with a rotatory motion until all the gas has been liberated and no further increase is noted in C. Allow the bottle A, which may have been slightly warmed by the hand, to stand a minute or two till it has acquired the temperature of the air, and after having brought the level of the water in D to the same level as C, the reading of the latter gives the volume of carbonic acid evolved. To this

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quantity must be added a small amount for the gas absorbed by the hydrochloric acid, which is approximately 4 c.c. according to the total quantity evolved. 1000 c.c. of carbonic acid at normal temperature and pressure weigh 1·97146 grammes, and correction, of course, has to be made for variations in temperature and pressure.

The author knows of no published tables for special use with this apparatus, and therefore it involves a good deal of calculation. Some few years ago, before the later forms of apparatus came into use, he used this calcimeter for about twelve months, with the aid of a special set of tables kindly lent by a friend, and obtained fairly good results with it, certainly as accurate and with much less labour than with any of the apparatus of the well-known Schrotter type in which the carbonic acid gas is dried by passing through some desiccating agent and allowed to escape, the difference in the weight of the apparatus, before and after the evolution of the gas, indicating the amount contained in the material under examination.

A later form of volumetric apparatus is that devised by Dietrich, of which a sketch is given in Fig. 12. The gas is measured over water in much the same way as by the Scheibler apparatus, but the water equilibrium is maintained by lowering the left-hand tube which is fixed to a clip sliding on a brass rod. Another feature of this apparatus is that the gas is made to pass through the coil of a condenser immersed in water so that it is maintained at a given temperature. Instead of afterwards correcting for variations in temperature and barometric pressure, a set of tables is provided for use with this instrument by which a variable amount of slurry is used, according to the temperature and pressure prevailing at the time. A further table is also provided, giving the corrections to be made for absorption of gas by the acid employed, the amount

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absorbed varying according to the quantity of gas evolved. The method of working is very similar to that of the

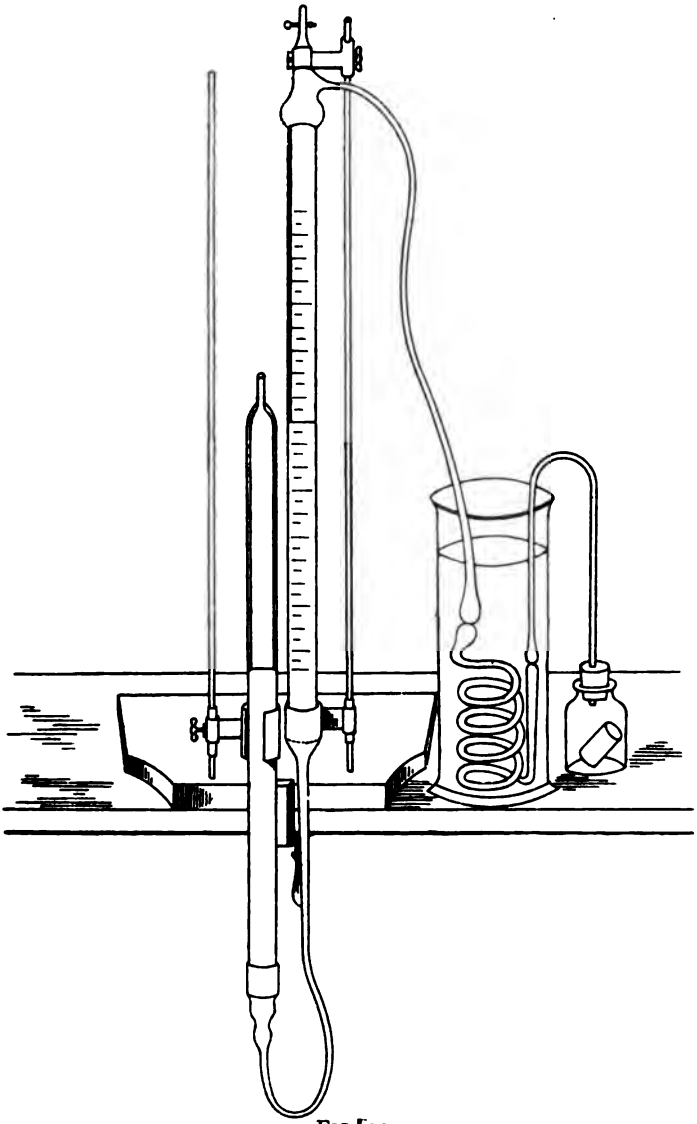

FIG. 12.

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Scheibler apparatus. The left-hand tube is raised until the water in the right-hand graduated tube reaches the zero mark on the scale. The left-hand tube will then be nearly empty. The slurry and the tube containing acid having been placed in the generating bottle in the usual way, and the stopper replaced, the tap at the top of the graduated tube is closed. The acid is then allowed to flow on to the slurry; as the gas is generated it depresses the water in the right-hand tube, and the left-hand tube is therefore correspondingly lowered so as to maintain the equilibrium. When the bottle has been thoroughly shaken to make sure that all the gas is liberated, it is placed in the condenser jar, where its contents are reduced to the temperature of the water therein. The reading of the scale plus the correction for absorption, according to the table provided for that purpose, gives the weight of carbonic acid evolved.

Fig. 13 shows a compensated variation of the Dietrich apparatus, specially devised by the late Henry Faija for use by cement-makers, the details of which have been very carefully considered, so as to render the working of the instrument as easy as possible. To avoid the necessity of correction by calculation for barometric pressure, an aneroid barometer is attached to the equilibrium tube, so that the pressure in the gas measuring tube may be thereby adjusted to the normal; by this means, the only factors affecting the volume of the gas that have to be taken into account are temperature and the amount of gas absorbed by the acid used. As previously stated, the latter varies with the volume of gas evolved and the amount of acid used, but if a given quantity of hydrochloric acid is always used, it is evident that the instrument may be so scaled as to allow for the percentage of gas absorbed. In this instrument the scale has been arranged to work with 0·35 fluid oz. or 10 c.c. of hydro-

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chloric acid. This only leaves the temperature to be taken into account, and a table is supplied by which the reading of the instrument at a given temperature gives

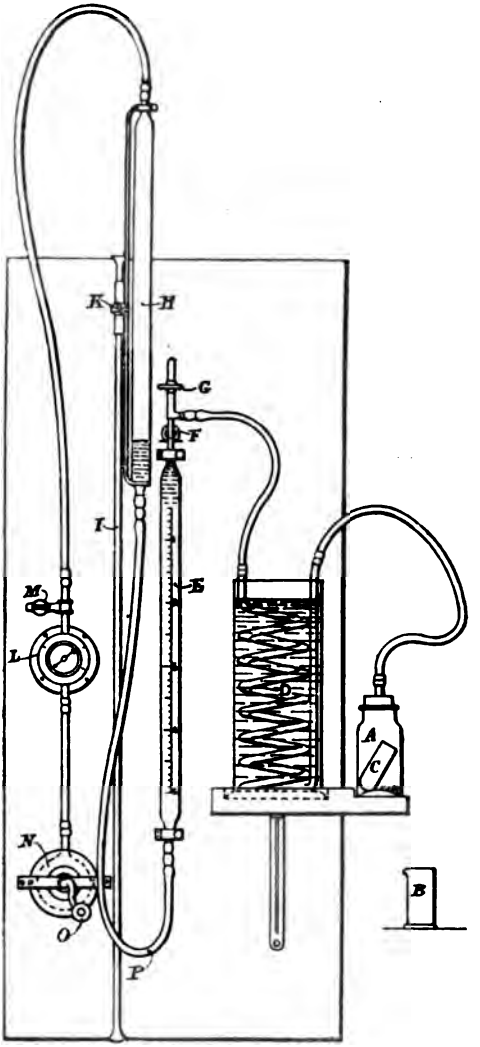

FIG. 13.

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the percentage of carbonate of lime in the slurry. The following is the adaptor's description of the instrument and its method of working.

A is the generating bottle.

B is the acid measure.

C is the gutta-percha acid tube.

D is the condenser with lead coil.

E is the gas-measuring tube, having at its upper end the two taps F and G.

H is the equilibrium tube, which may be moved up and down, and secured in any position, by fixing it on the rod I by means of the thumb-screw K.

L is the barometer, to which is attached on its upper side the tap M.

N is an india-rubber ball, attached by a tube to the barometer, which ball may be compressed or expanded by turning the handle O, thus adjusting the pressure in the instrument.

To set up the instrument, it is first necessary to secure it firmly against a wall, taking care that the tubes E and H are perfectly vertical. Then attach the india-rubber tube P, connecting the lower ends of tubes E and H. Tube H should then be lowered until its upper neck is a little above the lowest reading on tube E, a funnel inserted in the neck of H, and the tube filled with water until the water rises up to the lowest reading in tube E. When filling with water, the two taps F and G should be open, and as air is likely to accumulate in the india-rubber tube P this should be squeezed and pressed until the air is all expelled. The water used should be distilled water, and in order that all air may be expelled from it, it should be boiled and allowed to cool before pouring into the instrument. Then attach the other india-rubber tubes, as shown in the drawing, put the stopper into the

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generating bottle A, close taps G and M, and see if the connections are air-tight. This is ascertained by placing the equilibrium tube H in such a position that there is a difference of several inches in the level of the water in the two tubes E and H, and noting the reading of the level of the water in tube E; if the connections are air-tight, the water will remain at this level for an indefinite period. If, on the other hand, the water in E rises or falls, some of the joints are not tight, and they must be made tight by binding them with thin brass or copper wire. The condenser D should be filled with water.

Having ascertained that the instrument is tight, the mode of working is as follows:—

First remove the cork from the generating bottle A, and take out the acid tube C, then open the taps F, G and M. Elevate tube A to such a height that the water in tube E is exactly level with the mark immediately under tap F, and secure it there by turning the thumb-screw K. Weigh out the quantity of carbonate of which it is desired to determine the carbonic acid it contains, and place it in the generating bottle A. Measure out the proper quantity of acid to use, in the measuring glass B, and pour it into the acid tube C. Wipe the outside of the acid tube C, so as to be sure that no acid has run down the side and insert it, with a pair of tongs, into the generating bottle A. Re-insert the stopper in the generating bottle A, taking care that it is secure and tight. Close tap G, and take hold of the thumb-screw K with the left hand and slacken it, at the same time keeping the tube H approximately in its elevated position. Now take the generating bottle A in the right hand, and incline it so that the acid runs out of the acid tube C, on to the carbonate in the bottle A, and as the gas is generated, lower tube H, so as to keep the water in tubes E and H approximately at the same level. Continue

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shaking the bottle while the gas is being generated, and be sure that all the acid has run out of the acid tube C. Place the generating bottle A into the water in the condenser D; this is to cool the gas, which might have been heated by the handling of the generating bottle A, down to the temperature of the water in the condenser D. Having left it there for a minute or so, remove it, and again shake it, and note if any more gas is generated. When all the gas is generated, which is indicated by the water in tube E remaining in a constant position, close the taps F and M, turn the handle O actuating the ball N, in either one direction or the other, so that the pressure in the barometer is diminished or increased, and it indicates the normal pressure of 29·92 inches, or 760 millimetres, which is shown more distinctly by the heavy line on the dial. Adjust tube H, so that the water in it is exactly level with the water in tube E, and take the reading of the level of the water in tube E. This reading is the amount of gas developed at the standard pressure, and simply requires correction for temperature, which may be ascertained by the tables, as already explained.

When using the instrument the thermometer should be placed and left in the water in the condensing vessel D, as it is the temperature of this water which governs the temperature of the gas; but it is as well to try and adjust the temperature of this water to approximately the temperature of the atmosphere of the room in which the instrument is worked.

Before commencing an experiment, the reading of the barometer should be ascertained, and if above 29·92 inches or 760 millimetres, the ball N should be compressed, so that by turning the handle O and allowing it to expand, the pressure in the barometer will be decreased. If, on the other hand, the barometer is below 29·92 inches or 760

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millimetres, the ball N should be left fully expanded, so that by turning the handle O, and compressing it, the pressure in the barometer will be increased.

The author used this apparatus continuously for two years at a cement works, and always found it a very reliable instrument. There are one or two points, however, which need attention. In the first place, care should be taken that the graduated tube containing the carbonic acid gas is not warmed by the rays of the sun or fire, as the volume of the gas would thereby be increased and give an erroneous reading. It is also as well, as above stated, to maintain the water in the condenser vessel at approximately the same temperature as the air in the room.

Another method of estimating the carbonate of lime in a slurry, which is largely used in Belgium and Germany, and seems to be finding a certain amount of favour here is by titration with a standard solution of hydrochloric acid, i.e. ascertaining how much hydrochloric acid of known strength is required to neutralise the carbonate of lime.

For this purpose 0·5 gramme of the carefully dried and powdered slurry are weighed into a titrating flask and covered with about 50 c.c. of distilled water ; 20 c.c. of semi-normal hydrochloric acid are carefully added, and after effervescence has practically ceased, the solution is raised to boiling point and kept boiling for two or three minutes to expel all carbonic acid ; two or three drops of phenolphthalein are added and then a solution of semi-normal caustic soda is slowly run in from a graduated burette, until the liquid turns red or purple, indicating that the excess of hydrochloric acid present has become neutralised. The amount of soda solution required to attain this result is then carefully read off, and the excess of acid thus ascertained ; the number of c.c. of acid used to neutralise the slurry, multi-

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plied by 5, gives the percentage of carbonate of lime present. The advantage of this process of slurry testing is that there is no barometric pressure or temperature to be taken into account, but it requires rather more careful manipulation and chemical knowledge than the calcimeter, which can be used by any works foreman.

It will be found that a regular and systematic method of testing the slurry will fully pay for the time and trouble involved in making the tests; in fact, in no other way can reliable results be obtained from the materials under treatment. If the percentage of carbonate of lime is allowed to fall below a certain limit, the strength of the resulting cement is generally seriously impaired, whereas, if the percentage rises too high, an unsound, dangerous cement would result, and one that might bring all sorts of unpleasantness in its train, both for the manufacturer and the user. It is needless to remark that, of the two evils, excess of clay is far less dangerous than an excess of chalk, as the former merely results in a somewhat weaker cement, while the latter might cause the utter destruction of any work in which the cement was employed, and thus involve the manufacturer in heavy claims for damages. If the slurry is much too low in carbonate of lime, it will be found that the mass of the clinker, especially if thoroughly burned, will have a tendency to spontaneously disintegrate and fall to powder on cooling, thus choking the draught and spoiling the burning of the upper portion and remainder of the contents of the kiln. According to Le Chatelier, this is due to the formation of certain crystals of di-calcic silicate; if the clinker is somewhat under-burned, and the calcination is not carried to incipient vitrifaction, these crystals are not formed, and the above-mentioned phenomenon is not produced. Those conversant with cement manufacture have doubtless noticed that when a "burr" or extremely hard-

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burned, partially fluxed piece of clinker, has been got out of the kiln while still very hot, and allowed to cool, the mass will often gradually disintegrate, and if burned sufficiently hard, will ultimately be reduced to a heap of bluish-grey dust.

The plan adopted by the author for sampling the slurry was as follows. The man in charge of the wash-mill was provided with a large earthenware vessel of about one quart capacity and several smaller ones of about half a pint; a slide or shutter was made to fit into a groove cut in the square wooden shoot leading from the wet stones to the pumps, so that by sliding in the shutter, the flow of the slurry was arrested, and a pool formed of sufficient depth to enable a dip to be taken with a small ladle. Every quarter of an hour a samply of slurry was taken from this shoot and placed in the large pot called the "average" pot, so that at the end of the day it contained an average of the day's working. In addition to this average sample, a sample consisting of three dips taken at intervals of five minutes was taken every three hours during the day, and together with a small sample from the average pot, sent up to the testing room. This method enabled a correct knowledge to be gained of the percentage of carbonate of lime in the slurry at stated periods in the day, and also the average of the day's washing up to that period.

In taking the sample of slurry for testing purposes as it leaves the wash-mill, care must be taken that the sampie thus procured fairly represents the bulk. It is scarcely safe, for instance, to dip a ladle into the surface of the stream of slurry as it flows along the trough or shoot, more especially if it has been flowing some distance. In such a case, the coarser particles of chalk would have a tendency to gravitate to the bottom, and thus a sample taken from

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the surface of the stream only would be misleading. It is better in such cases to adopt some modification of the sliding shutter arrangement above described, by means of which the whole of the flow is temporarily arrested, and a fair average sample procured. For drying slurry quickly for testing purposes, tin patty pans about 3 inches in diameter will be found very convenient, as they can be placed directly over the gas or other heating surface, and heated quickly without fear of breakage. Care must be taken, however, that the slurry is not exposed to too strong a heat when nearly dry, or some of the carbonic acid may be driven off, which would of course lead to an erroneous result when tested by the calcimeter.

There is one item, however, which must not be lost sight of in estimating the carbonate of lime in the slurry, and that is the amount of organic matter contained in it. It is very evident that if a slurry contains say 3 per cent. of organic matter, which would be lost in burning, in addition to the carbonic acid, the actual lime in the calcined product would be proportionately higher than if the slurry contained only 1 per cent. of such organic matter. Where facilities exist, therefore, it is as well to occasionally estimate the loss at red heat, in addition to the amount of carbonic acid, as it serves for a check on the calcimeter, and where that instrument only is used, also tends to prevent unintentional overliming, consequent on variations of organic matter in the clay.

The correct proportion of carbonate of lime in the slurry depends, firstly, on the chemical constituents of the raw materials, i.e. the proportions of silica and alumina in the chalk and clay, and secondly, on the thoroughness with which the several processes of manufacture are carried out. As will be demonstrated hereafter, a thoroughly washed, perfectly calcined and finely ground cement will bear with

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safety a considerably greater percentage of lime than one which has been less efficiently prepared. The usual practice is for the dry slurry to contain from 75 to 77 per cent. of carbonate of lime, according to circumstances; and most manufacturers, having found by experience the exact percentage which gives the best results with their materials and method of manufacture, endeavour to adhere as closely as possible to that percentage. It must not be forgotten that, although the estimation of carbonic acid in a slurry serves to control the amount of chalk used, the composition of the resulting cement does not by any means correspond exactly with that of the slurry, after deducting the carbonic acid therefrom and calculating the residue to 100 parts. One factor which largely affects the composition of the resulting cement, is the ash of the coke or whatever fuel may have been used for calcination. The following table of analyses, recently made by the author to investigate this question, gives the percentage and composition of the ash of six different samples of coke, taken from various cement works on the Thames and Medway.

—	Percentage of Ash.	Percentage of Insoluble Matter in Ash.	Composition of Ash.						
			SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	SO_3.	Other Constituents.
Coke, No. 1	10·0	51·9	35·67	29·41	17·30	6·50	2·23	6·70	2·17
„ 2	8·2	37·0	33·25	26·43	27·50	5·70	1·13	5·06	0·97
„ 3	7·3	51·9	31·31	27·08	27·58	6·87	2·27	1·73	3·16
„ 4	9·7	49·1	34·79	28·21	10·35	12·32	2·71	8·09	3·53
„ 5	12·0	62·2	47·86	28·99	10·25	6·76	2·67	1·76	1·71
„ 6	7·2	41·9	34·62	23·55	18·60	9·25	3·35	8·04	2·59

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It will be seen that the ash consists chiefly of insoluble silicate of alumina and iron, some samples also containing a marked quantity of sulphuric acid. As it takes from five to ten cwt. of coke to calcine a ton of cement clinker, according to the type of kiln used, it will be readily seen that the ash has a considerable effect on the ultimate composition of the cement.

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CHAPTER IV.

DRYING FLOORS AND KILNS.

HAVING by means of wet mills reduced the raw materials to the requisite mechanical mixture, the next step in the process of manufacture is to drive off the water it contains, and then, by calcination to incipient vitrifaction, convert the mixture into its proper chemical compounds. The chemical reaction which takes place on calcination is that the carbonic acid in the chalk or carbonate of lime is first driven off, and when the requisite degree of temperature to cause incipient vitrifaction is reached, the resulting lime combines with the clay or silicate of alumina to form silicates and aluminates of lime. With the original system of backs, it was usual to dry the slurry on drying floors, heated by coking ovens, so that the waste heat from the coking ovens was utilised for drying purposes, the coke produced being used for calcining the clinker. This system is now practically obsolete, the drying being almost universally effected by utilising the waste heat from the kilns, which in the older factories was allowed to escape unutilised. Where Dietsch kilns are used, however, and others of a similar nature, that cannot be adapted for drying the slurry, separate drying floors have to be made use of, and a description of them, therefore, may not be out of place.

The drying floor should be of such a capacity that it will dry in twenty-four hours as much as is required for

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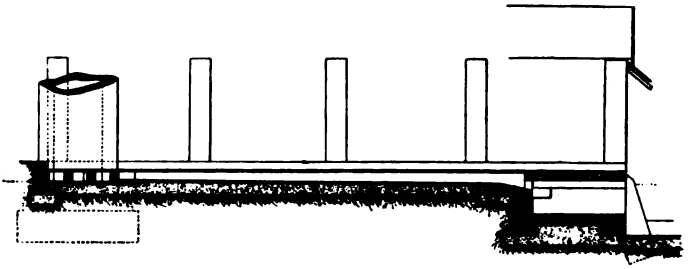
the day's work; if one kiln of 25 tons of clinker output is to be loaded per day, the floor should be capable of drying its equivalent of the raw slurry, i.e. about 37 tons, the stripped portion being covered with fresh wet slurry as fast as the dried material is taken off, so that no heat may be lost.



SECTION A. B.

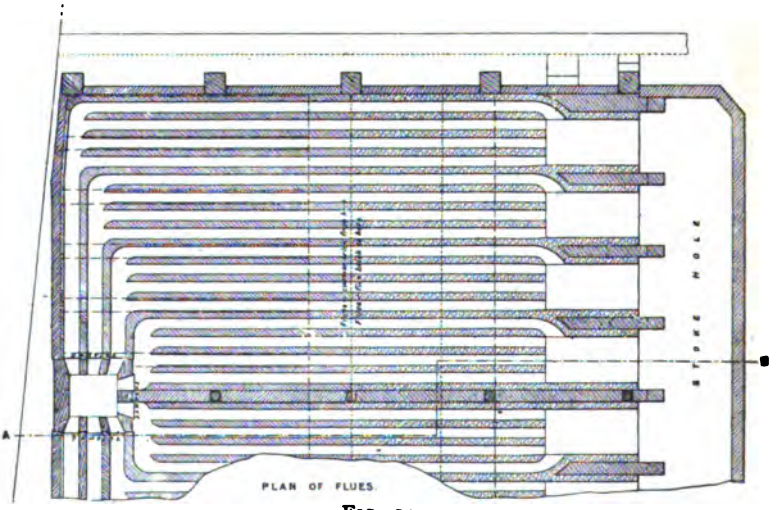


FIG. 14.

An illustration of a drying floor of the usual design, reduced from a working drawing is shown in plan and section in Fig. 14. It consists of a series of coke ovens or other convenient furnaces from which flues lead to a number of

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chimneys, or a large central chimney, according to circumstances. These flues are about one foot wide and one foot deep, with 9-inch brickwork between them, and for the first twenty feet from the ovens they are built of fire-bricks and covered with fire-tiles, this construction being necessary to resist the intense heat generated by the ovens or furnaces; the further ends of the flues, or tails as they are generally called, are covered with cast-iron plates about 1½-inch thick. The greatest heat of these flues, of course, is immediately over the ovens or furnaces, and in covering the floors with slurry it is necessary to put the greatest part of the load over the ovens, gradually reducing the thickness towards the tail end, where the heat is not so intense; by this means the whole of the load is dried and ready for removal practically at the same time. As covering and stripping the floors and loading the kilns is generally piecework, i.e. so much per ton, it is the aim of the man who undertakes the covering of the floors to so arrange the load that all of it is dry by the time the strippers come to it, and of course at the same time to get as much dry as possible.

The coke ovens, which are drawn and recharged every twenty-four hours, are generally loaded with fine coal, the quantity and quality of the coke produced therefrom varying according to the quality of the coal used. Drying floors are sometimes arranged to be covered throughout the greater part of their surface with steel plates, and the flues made wide and deep, so that they can also be filled with slurry, which is dried by the heat passing over it. This arrangement works very well where backs are used, and the slurry to be dried is somewhat stiff, but with the semi-wet process where the slurry is of a more fluid nature, some difficulty is experienced in keeping the joints of the plates sufficiently tight to prevent leakage into the pits.

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As these plates have to be taken off every time the contents of the pits are removed, there are obviously not the facilities for keeping a tight joint as when they are permanently fixed in one position, and unless care is exercised, the leakage into the pits will sometimes be sufficient to stop the flues altogether. A similar arrangement of pits is sometimes used in the drying chambers of kilns, to which the same objections may be urged.

The original form of kiln used for calcining cement is shown in section in Fig 15, which is reduced from a working drawing; although it is far from economical, inasmuch as all the waste heat is allowed to escape, the clinker resulting from this kind of kiln is probably better than that burned in closed chamber kilns, which utilise their waste heat for drying the next load of slurry. The outer structure of the kiln may be built of brick, stone, concrete or any convenient material at hand, but its lining, owing to the great heat to which it is subjected, must be of fire-brick. It is found advantageous, if the kiln is built of stone, concrete or other material than brick, to place a good back lining of ordinary brick behind the fire-brick lining to minimise the effect of the heat upon the stone or concrete. Moreover, when the fire-brick lining gets burnt out and has to be renewed, the back lining serves as a contour for the bricklayers, and the new lining has only to be laid up against the back lining instead of having to use a template.

The part of the kiln lining which will be found to require most repairs and attention is that which is directly exposed to the reducing action of the white hot clinker. As the bulk of the charge shrinks to about one-half after calcination, owing to the expulsion of the carbonic acid in the slurry and the combustion of the coke, and the fire commences at the bottom and gradually works up, it is very evident that only the lower half of the lining is ex-

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posed to the reducing action above mentioned. In order, therefore, to protect the lining as much as possible from

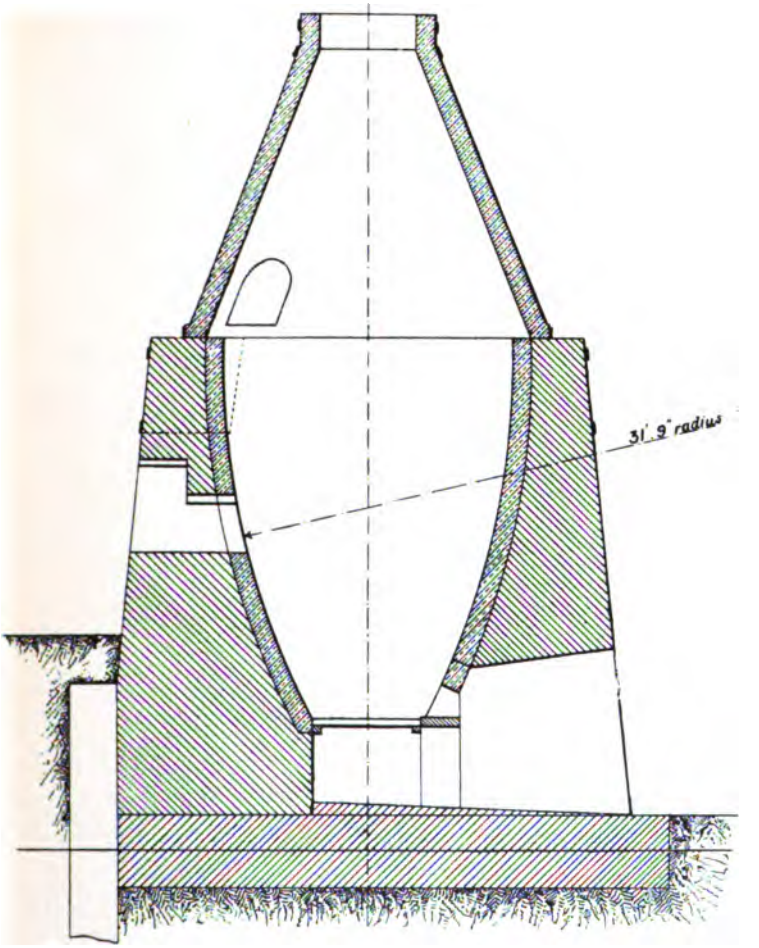

FIG. 15.

this reducing action, it is usual, after the kiln is drawn and before the next load is placed in it, to daub the lower part of the lining with wet slurry or similar material, which acts

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as a protective skin, and greatly prolongs the life of the fire-brick.

In loading a kiln, the first step is to place sufficient wood and coke on the fire-bars to start the fire; then the dried slurry and coke, or whatever fuel may be used, are loaded in alternate layers, the quantity of fuel decreasing towards the top. The proper loading of a kiln is quite an art in itself, and is generally undertaken by the man in charge of the loading gang. Most kilns will be found to have little peculiarities of their own, and it is the burner's duty to watch the clinker as it is being drawn, and note if any portions are under or over burned, so as to be able to correct any error in the next loading. In most kilns the greatest draught is in a line from directly over the drawing eye upwards, and naturally where the draught is greatest the least fuel is required. Generally speaking therefore, it is found necessary to place the greatest portion of the fuel round the outside of the kiln, the centre, where there is most draught and less cooling influence, requiring comparatively little. The time which a kiln takes to burn off depends upon its size and shape, and upon the draught, whether natural or forced. Another potent factor is the direction and force of the wind; obviously, if there is a strong wind blowing directly into the drawing eye, it acts as a forced draught, and consequently the sooner the kiln burns off; wherever possible, therefore, the kilns should be so arranged that the drawing eyes face in the direction of the most prevalent winds.

Sometimes, owing to peculiarities of loading or other reasons, a kiln "hangs up," or "goes to sleep," i.e. the materials in settling down, form a dome or arch of clinker, which is almost impervious to the draught, and unless vent is given and a hole made through this dome, the fire will take days to get through it, if indeed the kiln does

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not go out altogether. If, after being alight a day or two, a kiln is found to be progressing very slowly, and little or no smoke issuing from it, it is generally an indication that it is "hung up," and steps must be taken to pierce an opening through the obstruction. This is generally accomplished by opening the loading eye above, and running a long pointed iron bar of about 1½-inch diameter down through the mass, until the obstruction is penetrated and free draught reinstated. It is not sufficient to simply make a hole through the obstruction; the unburnt contents of the kiln overlying it should be got down, till the hollow space which will be found under the dome in question is filled up, so that, as the burning progresses, the contents of the kiln may fall in regularly and evenly.

The fuel most commonly used for burning cement is ordinary gas coke, and this is the most convenient fuel for the type of kiln generally used in this country. Unsuccessful attempts have been made to use wood or charcoal in localities where the cost of coal or coke was almost prohibitive; apart from the enormous quantities required to obtain anything approaching clinkering temperature, the results proved decidedly discouraging. When coke supplies are short, as sometimes happens in the summer months, substitutes have to be used, and of these, hard anthracite coal is found to give the best results. The chief objection to coal, however, is that, although the kilns hold more slurry, owing to the coal being considerably heavier, and therefore occupying less space than coke, it retards their output to a large extent, being very much slower in burning than coke. It also requires rather different manipulation, and although good results have been obtained by the author with kilns using nothing but coal for calcination purposes (except a few bushels of coke at the bottom to start the fire), he always found that a burner who was

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used to coke, required considerable practice before he could get equally good results with coal. While on this subject, it may be said that the burning of cement requires a good deal more judgment and experience than is generally recognised; to load a kiln properly, is really as much skilled labour as that of a fitter or mechanic. Where ordinary open or bottle kilns, without drying chambers attached, are used, it will be found a great advantage when using coal as fuel in them, to improve the draught by increasing the height of the dome or chimney by a few feet; a small outlay in this direction will be found to materially increase the output of the kilns.

Coming next to the several varieties of combined kilns and drying floors—or to be more accurate, kilns of which the waste heat is utilised for drying the slurry or slip—although there are several cement works in England which claim to have been the first to erect and use kilns of this description, the first manufacturer to adopt them to any great extent was Mr. I. C. Johnson, of Greenhithe. It may therefore be of interest to reproduce the illustration and quote from his original patent, No. 1583, of 1872, in which he describes his invention and claim as follows :—

"The invention consists in constructing the drying chambers of a rectangular or other corresponding shape, and with the roof of semicircular or equivalent form springing from the floor or near thereto. One end of the chamber is open to the heat from the kiln or furnace, and the products of combustion pass over instead of under the mass to be dried, and find an outlet into a chimney at the opposite end of the chamber through a door in which the material is preferably inserted. The chamber is sufficiently high for men to work in, and may be placed in connection with coke ovens, kilns, or other heating appli-

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ances, so that the waste heat in passing over the mass can be utilised before passing into the chimney.

"The floor of the chamber may be slightly inclined towards the front to induce the mass to flow down it, and so become more and more exposed to the top heat which is passing through the chamber in an opposite direction.

"I prefer to arrange the drying chamber about level with the top of the cement burning kiln, so that the mass, when sufficiently dry, can be scraped or pushed over a ledge or bridge into the kiln direct (by men in the chamber) to be burnt in the ordinary manner.

"Several drying chambers may be used in connection with one kiln to divide the heat if desired.

"The upper part *a* of the kiln *b* is built with a flat rim, and is covered by an arched roof *c* to put the kiln into communication with the chimney and smoke vapour outlet *d* by a long horizontal chamber or flue *e* with a flat or slightly inclined floor, upon which the wet slip or slurry is placed or allowed to flow from the chimney end at *f* where an aperture *g* provided with a door is situated for its reception from trollies, barrows, boxes, or other articles as found convenient. The roof of the chamber *c* is of semi-circular, segmental, or semi-elliptic form, and the crown is sufficiently high to enable a man to move along and spread or level the wet slip upon, and also to remove the dry cakey slip from the flooring into the kiln *b* or into a receptacle.

"The chamber may be of any length, and it may be divided or broken up so that the smoke and vapour from the kiln would travel in a zigzag or circuitous route to utilise the whole of the heat in drying before it escapes up the chimney. . . .

"The features of my invention, and to which I lay claim, are—

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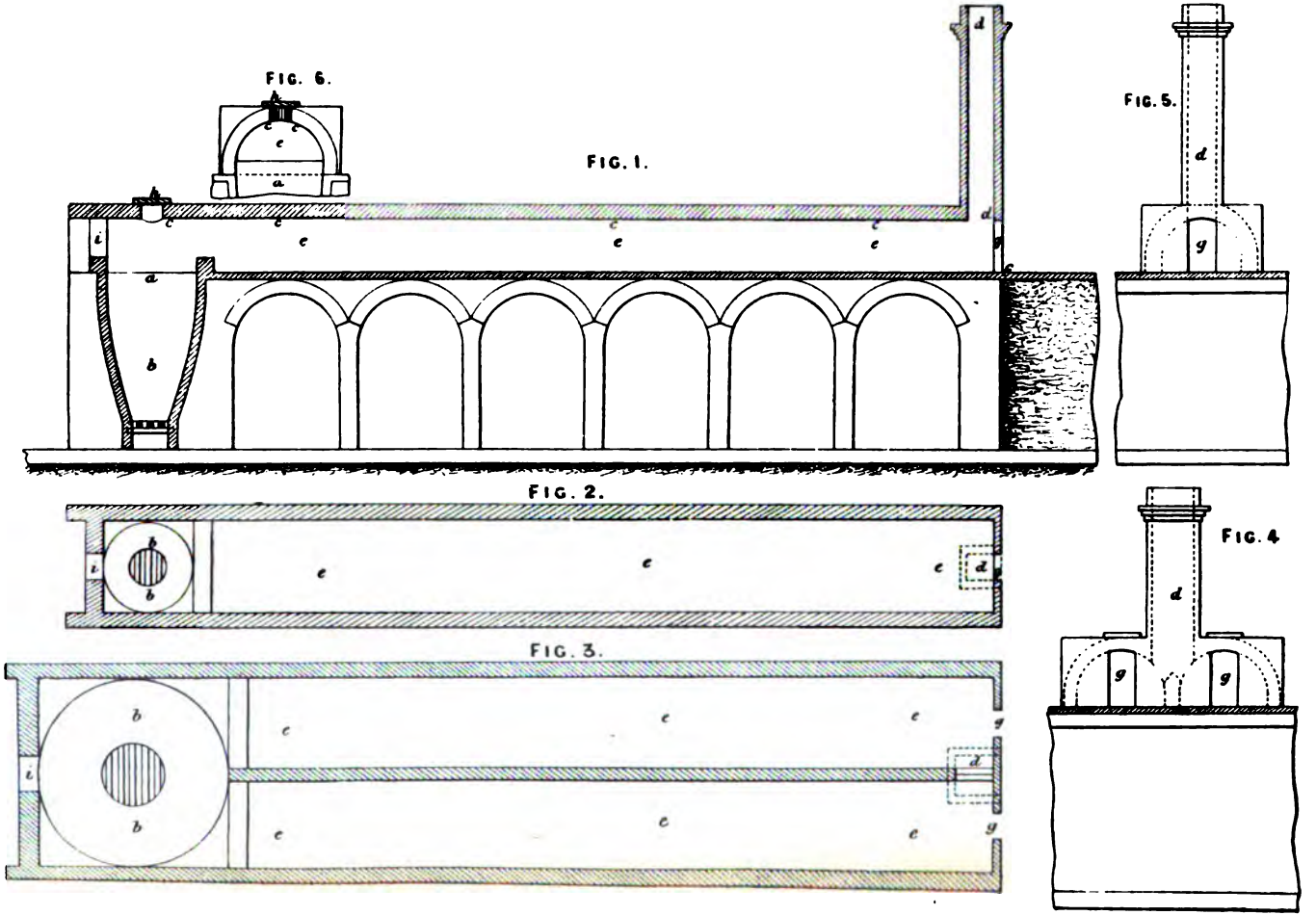
FIG. 16.



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"Firstly. The direct or top drying of slip or slurry from which cements are made, and also other bodies of a semi-liquid character, by the waste heat and vapours given off from kilns, ovens, and other heating apparatus when such drying is effected in chambers large enough for men to move in between the heating apparatus and the chimney substantially as described and shown.

"Secondly. I claim the construction of semicircular or equivalent shaped chambers or flues with flat floors, upon which semi-liquid bodies used for cements can be dried as described and shown.

"Thirdly. I claim dividing or partitioning off spent heat flues or chambers in which men can move, and the drying of semi-liquid bodies therein as described.

"Fourthly. I claim the combination of a horizontal flue or passage with a cement burning kiln when such flue is used for drying by passing the heat over the material to be burnt in such kiln, as also the means of regulating the draughts substantially as described and shown."

From the illustration it will be seen that the kiln consists of an ordinary bottle kiln, but without the high dome or chimney, and with a long horizontal chamber attached; this chamber is semicircular in section and at its further end is a flue with dampers leading to the chimney shaft. The wet slurry is laid on the floor of this chamber and is dried partly by the waste heat from the kiln passing over it, and partly by the radiated heat from the brickwork of the arch. As in the case of the drying floors, the first few feet of the chamber nearest the kiln have to be built of fire-brick, to withstand the intense heat given off by the white hot clinker, the further end being built of good ordinary brick. The floor of the chamber is arranged at such a slope that the slurry is about a foot or fifteen inches thick next the kiln, and gradually decreases towards the flue end of the

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chamber, where it is only three or four inches in depth. With the floor properly arranged in this manner, the slurry only has to be allowed to flow into the chamber, and it will then find its own level, requiring no superintending and levelling as in chambers that are not so arranged.

The most serious item of expense in constructing the Johnson and similar types of kiln, is that the chamber being at the level of the top of the kiln, must necessarily be carried on arches or pillars, or some such structural arrangement, which entails a considerable expense in building. In works which are built at the foot of a chalk slope such as those of the inventor at Greenhithe, this objection does not of course hold, for the kilns being built at the foot of the slope the chambers are carried on the chalk, the excavated chalk being used for the manufacture. Where this can be done the cost of the kiln is greatly reduced, although where the chambers have to be carried on arches, these arches can be advantageously utilised for stores of various kinds.

The main principle of the Johnson kiln is that it dries the slurry by the heat passing over it and by the radiated heat from the arches of the chamber, and to this method some objection may be urged, inasmuch as a good deal of alkali and other matter volatilised during the burning of the kiln is cooled and deposited on the slurry in the passage of the fumes through the chamber, and is loaded into the kiln again with the next charge. Although these objections are not serious, they detract somewhat from the ideal nature of the kiln ; this difficulty may be obviated by constructing flues leading from the kiln under the slurry, so that the products of combustion pass directly to the chimney without coming into actual contact with the slurry. Where this method is adopted it is usual to do away with the arched chamber altogether, and merely throw a light roof over the floor to

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keep off the rain. This system also has its advantages and disadvantages, for although such open drying floors are much less trying for the workmen than the closed arches, great care has to be exercised to prevent leakage of slurry into the flues. If leakage takes place to any considerable extent, it will not only entirely stop up the flue, and so prevent the slurry drying along that particular flue, but will sometimes run forward down into the kiln, and altogether spoil the burning.

The actual loading of the kiln is accomplished in various ways, almost every works having a system of its own, the principal aim being to combine economy in labour with excellence of results. In the chamber kilns which have just been described, it is usual to wheel the dried slurry in barrows along a double 14-inch plank thrown from the chamber across to the opposite edge of the kiln, and tip it into the required position ; the burner stands below at the coke loading eye, directs where each load is to be tipped, and throws the coke on at the proper spot. In some works, instead of tipping the slurry direct from the barrows, four baskets, each of about half a bushel capacity, are placed on a flat barrow for ease of transport, and the contents thrown as the burner directs. In this way, of course, the slurry can be more widely distributed, but the author has had charge of works where slurry was tipped direct in barrow-loads and the resulting clinker was all that could be desired. Of course, where the loading is carried on in this manner, it is imperative for the burner to take proper precautions that the slurry is not tipped into the kiln in pieces of too large a bulk, and also that none is used which is not sufficiently dried. In the first instance, the calcination will be incomplete owing to the bulk being too great for the heat to penetrate thoroughly ; and in the second instance the calcination will be incom-

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plete in the centre owing to the slurry not being dried, and the heat that should have been used to calcine it, having been partially expended in driving off the water.

The method that is generally adopted where the slurry is handed into the kiln from the drying floor, is to load the kiln in so many rounds or layers, consisting of so many barrows or baskets of slurry to so many barrows or baskets of coke, the proportion of coke, as before mentioned, being greatest at the bottom, and gradually diminishing towards the top, the proportion of slurry increasing in a corresponding manner. The following may be given as an instance of the manner in which a chamber kiln is loaded, the rounds or layers showing the gradual decrease in the amount of fuel towards the top. Sufficient faggots to start the fire are laid on the fire-bars, and then thirty-five baskets of coke placed thereon, the subsequent rounds consisting as follows :—

2	rounds of	16	loads of slurry	to	20	baskets of coke.	
5	„	10	„	„	10	„	„
6	„	12	„	„	8	„	„
10	„	16	„	„	10	„	„
19	„	20	„	„	12	„	„
2	„	20	„	„	13	„	„
3	„	20	„	„	14	„	„

Kilns loaded in this manner consume rather more than 8 cwt. of coke per ton of clinker, and no trouble is experienced in the drying of the slurry. This quantity of fuel is exceeded in some works, while in others it does not amount to so much, everything of course depending upon the draught of the kilns and other conditions prevailing. The quality of the coke used also largely governs the amount necessary for proper calcination. During the coal strike some few years ago, the gas companies were compelled to use whatever coal they could obtain, and the

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consequence was that some of the coke that came into the hands of cement manufacturers was of very poor quality, as the author remembers to his cost.

Where separate drying floors are used, and the slurry has to be handed up into the kilns, round wrought-iron tins, or "pannikins" as they are called, are sometimes used instead of baskets; they contain rather more than a cubic foot of dried slurry, four of them being placed on a flat barrow for wheeling to the kiln. Such pannikins are of convenient size and weight for handling up into the kiln, as where the drying floor level is only slightly above the fire-bar level of the kiln it necessitates a great deal of lifting towards the end of the loading. The following may be quoted as an example of the loading of an ordinary twenty ton bottle kiln, with open dome and no drying chamber attached (see Fig. 15). Forty baskets of coke were placed on the faggots, and the rounds then consisted of:—

8	pannikins	of slip to	11	baskets	of coke.
8	„	„	10	„	„
12	„	„	13	„	„
12	„	„	12	„	„
16	„	„	17	„	„
16	„	„	17	„	„
20	„	„	18	„	„
24	„	„	20	„	„

It will be noted in this instance, that the layers not only gradually decrease in the quantity of coke used, but also gradually increase in the thickness of the rounds, i.e. from 8 to 24 pannikins per round.

In the burning of kilns where the waste heat dries the next load of slurry, great judgment is necessary in the manipulation of the dampers leading from the chamber to the chimney shaft. For the first day or so after the lighting of the kiln there is not much heat given off, and

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the dampers are allowed to be fully open, so as to get the kiln into fire as soon as possible; as it gets into full fire, the dampers should be checked gradually, and finally left only just sufficiently open to draw the fumes away from the kiln, the object being to retain the heat in the drying chambers as long as possible. It will be readily understood that if the dampers are left wide open while the kiln is in full fire the hot gases will go roaring away up the chimney, and the kiln will in all probability be burnt out without the slurry in the chamber being properly dried.

When slurry is dried by the heat passing over it and by radiation from the brickwork, it generally shrinks and cracks open in large fissures, thus enabling the moisture to escape. The author once had a very unpleasant experience when the works of which he was in charge ran short of water during a very dry summer, and as barely sufficient fresh water could be procured for the boilers, salt water had to be used for the wash-mills. It was found when using salt water, that the slurry very rarely dried satisfactorily in the kiln chambers, and further, never seemed to shrink and crack open. On closer examination, it was noticed that the lower part and general mass of the slurry had shrunk and cracked in the usual way, with the exception of a skin of about half an inch or so on the top, which on analysis proved to contain a large quantity of salt. It is well known that when wet slurry has been allowed to stand a few hours, the chalk and clay composing it having a considerably higher specific gravity than water, the water separates and rises to the surface. In this instance, it was evident that the water on evaporating had left a crust of solid saline matter which sealed over the cracks, and as the steam was thereby prevented from escaping, of course, the slurry could not dry. It is, therefore, obvious that for chamber kilns where the slurry is dried from the top by

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radiation and by the heat passing over it, salt water should not be used for washing purposes. Of course, where it is dried on drying floors or by means of flues underneath, the use of salt water does not so much matter, inasmuch as the slurry begins to dry from the bottom, and the steam bubbles through the mass and is thereby forced to escape.

When the drying chamber of a kiln is designed to dry the slurry solely by radiation and the heat passing over it, there is not much variation possible from the original plan adopted by Johnson, but there are several modifications of the underneath flue arrangement, or of the two arrangements combined, which form the subject of numerous patents. The author's experience is that where the drying is done by underneath flues only, and the hot gases are led direct from the kilns into these flues, the area of the kiln being so much greater than the area of the flues, the heat is so concentrated at the entrance to the flues, that the brickwork very quickly perishes at that point. Where a sufficient draught can be obtained, a better plan is to combine the Johnson type of chamber with the underneath flue system, leading the hot gases over the slurry to the further end of the chamber, as in the Johnson kiln, and afterwards down into a series of flues which pass under the slurry back towards the kiln, returning again to the tail end of the chamber and thence to the chimney shaft. By this means the gases from the kiln have ample vent into the chamber, instead of being more or less confined in the kiln by the small flue area. The wet slurry being attacked by the heat both above and below, dries much better, and moreover, the gases having to travel the length of the chamber three times before they finally make their escape, nearly the whole of their heat is expended in doing useful work.

From a working point of view, and so far as regards

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cost of maintenance and repairs, the Johnson type of drying chamber is the most simple and satisfactory, as there are no flues to be blocked up by leakage of slurry or other causes, and no expense in repairing these flues and their necessary covering-down tiles, which in some cases is no small item. Whether it is preferable to have the chamber in one broad arch, or to divide it longitudinally into two narrow ones, is a point that is open to discussion. It seems a reasonable conclusion that the two narrow arches, being of smaller span, would bear the expansion and wear and tear better than the one broad one, and also that the central wall would assist in retaining and radiating the heat for drying purposes. On the other hand, the slurry would have to be spread slightly thicker to compensate for the space occupied by the central wall, and, owing to the heat retained by that wall, the two narrow chambers would probably not be workable by the strippers quite so soon as the one broad one.

A type of kiln that has lately been considerably adopted in the Thames and Medway districts is the Batchelor patent kiln, of which an illustration is given in Fig. 17. The principal feature of this kiln is that the drying floors are arranged in two tiers, one above the other, with flues under the floor of the lower tier, so that the wet slurry in each tier is attacked by the heat both above and below. Although the author has not had any personal experience with this kiln, he believes it answers very well both as regards the calcination of the clinker and the drying of the slurry. An objection which has been raised to this arrangement is, that when the lower tier of arches requires repairing, it is extremely difficult of accomplishment without at the same time endangering the stability of the upper tier. Owing to the drying floors being arranged on the double decker system, the length of chamber of this kiln only requires

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to be rather more than half that of the ordinary Johnson type, and therefore when on a flat site, where the latter would have to be carried on arches or similar structures, it is somewhat more economical in cost of construction.

It will also be noticed that these kilns are fitted with the fire-brick grating arrangement patented by Mr. George Burge, which has also been largely used in conjunction with the Johnson chamber kiln. The floor of the kiln, instead of being fitted with movable fire-bars in the ordinary way, consists of perforated brickwork. By this means it is claimed that a better draught is obtained, and the wear and tear is considerably less than with ordinary fire-

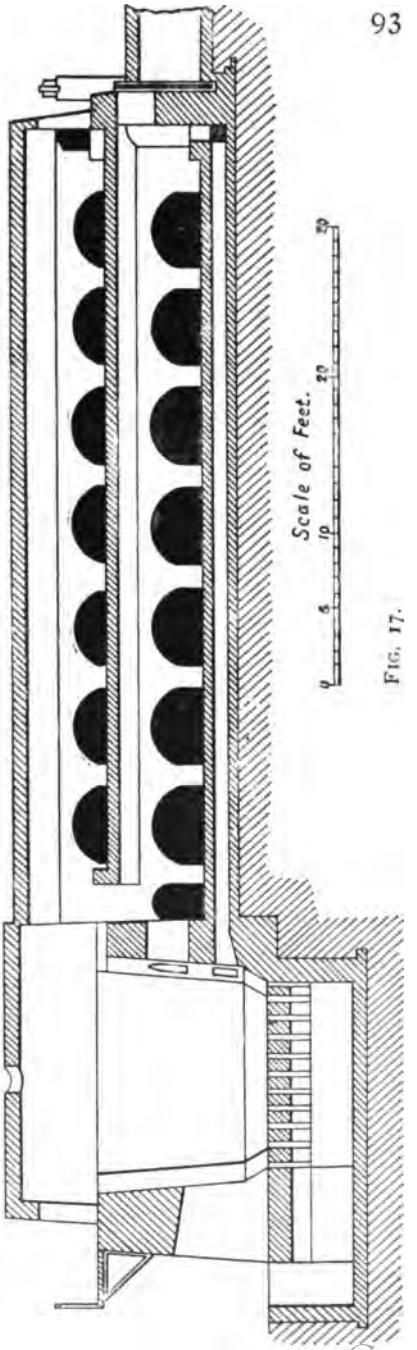

FIG. 17.

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bars. The author was assured by a manufacturer, a short time since, that he had fitted all his kilns with this type of grating, in preference to the ordinary fire-bars, although it is but fair to state that one instance of the reverse having taken place recently came under his notice. It will be seen that the grating is at ground level, and a sort of pit is arranged underneath for the double purpose of allowing air to enter and to enable the ashes and fine clinker which fall through the grating to be removed. The clinker is drawn out through an eye or opening at ground level in the front of the body of the kiln, which has to be bricked up and rendered practically air-tight with a plastering of wet slurry before the kiln is lit. The usual method of drawing kilns with these gratings is to lay an iron plate on the grating to form a shovelling surface, it being impossible to use a shovel satisfactorily on the uneven floor of the grating. This plate is gradually pushed forward, and the clinker falls on to it and is thus easily shovelled up into the wagon or barrow. A modification of this patent, which saves a good deal of labour though it is rather more expensive to erect, is to raise the grating sufficiently above the ground level to enable a small tram wagon to be placed underneath. The front part of the grating, for about three feet or so, is removed, and the opening fitted with short lengths of fire-bars which are removable in the ordinary way. When, therefore, a kiln has to be drawn, these fire-bars are removed and a wagon run in underneath the aperture thus formed, so that the clinker drops into it or is shovelled down off the grating, instead of being allowed to fall on to the floor of the drawing eye, as is the usual plan, and having to be lifted up thence into the wagons. Unless there is rising ground at the back of the kilns on which to carry the drying chambers, this modification is decidedly more expensive in first cost, as in order to get the same kiln capacity, the whole of the

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structure has to be raised proportionately, which in a series of kilns would mean a considerable extra amount of brickwork. Where a natural slope exists, however, the extra cost is not great, and it certainly saves a great deal of labour on the part of the drawers.

It has been stated in the preceding pages that the insufficiently burnt portions of the clinker are re-loaded into the kiln with the next charge, and burnt again to the proper state of incipient vitrifaction. When much of this underburnt is present in a freshly loaded kiln, it tends to slake and go to powder, which chokes the draught of the kiln, and spoils the calcination of the whole of the load. It is therefore sometimes found advisable to re-burn it in separate subsidiary kilns, and by some manufacturers this is claimed as an economy. Of course these kilns require very cautious loading, and only fairly large lumps can thus be dealt with, any dust or crumbling portions stopping the draught and altogether spoiling the burning; if such kilns are loaded with half-burnt in too fine a state of division, the mass will often smoulder for days without vitrifying at all, and the material comes out of the kiln very much in the same condition in which it was placed there.

Although for the fire-brick lining of the kilns and chambers, the ordinary 9″ × 4½″ × 3″ fire-brick is most commonly used, it is sometimes found advantageous to use bricks of a larger size, viz. about 9″ × 9″ × 9″, or fire-lumps as they are generally called. It will be readily understood that as one of these lumps occupies about six times the space of an ordinary brick, a great deal of time is saved in bricklaying, and moreover, there being considerably fewer joints, the fire has less opportunity of attacking the lining. Where there is a series of kilns, all of them exactly of the same size and shape, it is found economical to have the fire-brick for them made in lumps of special

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sizes, so as to fit the various parts of the kiln with practically no bricklaying ; for instance, segments to fit the arch of the loading eye, and the arch of the drawing tunnel, as well as other places where arches have to be turned. When these fire-lumps are ordered from the manufacturer in fair quantities, the cost is practically the same as for ordinary sizes, and the labour saved in repairing or relining a kiln is considerable.

It is usual to lead the products of combustion from chamber kilns into one tall chimney shaft, by which a good draught is secured, and the waste gases delivered at a sufficient altitude to avoid creating a nuisance. Where the latter is no object, an equally good, or even greater draught may be secured, by the use of a "Blackman" ventilating fan, built in at the end of the flues near the chimney and exhausting the kilns into it. It will be readily understood that where such forced, or rather exhaust draught is used, to render it efficient, great care must be taken that the kilns and chambers are practically air-tight, so that there is no leakage of air into them other than that which passes up through the kiln. The author is acquainted with one works where this forced draught has been adopted and is used with advantage. In this instance there are five large 35-ton kilns in one nest, having a cross-flue at the end of the chambers, leading to one common shaft, the draught being governed by two dampers to each kiln. As originally arranged, with ordinary draught, these kilns were each loaded once a week ; but with forced draught, it was found that by loading Monday's kiln with a somewhat lighter load, say 30 to 32 tons, it could be burned off and drawn on Friday, ready for loading with a full load on Saturday, thus obtaining an extra 30 tons output per week. In addition to this, it was found that with forced draught a considerable economy of fuel was effected, the saving ranging from 15 to 20 per cent. according

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to the draught employed. Of course there are many points to be urged for and against the use of forced draught. Its chief advantage is, that by varying the speed of the fan and the judicious use of dampers, it enables the draught to be increased or decreased as required. At starting, the maximum draught is put on, so as to draw the kiln up to a fire as soon as possible, but as soon as the kiln is in full fire, great care must be taken to avoid drawing the heat away from the chamber too quickly, only just sufficient draught being allowed to draw the heat forward from the glowing mass of clinker to the drying chamber. Nothing is more annoying than to find a kiln burnt off and the slurry for the next load only partially dried, and nothing is more extravagant than lighting up small loads in a large kiln, or making fires of coke or other material on top of the clinker to complete the drying of the slurry.

The size and shape of a kiln depend entirely upon the desired output and the site on which it is to be erected. For general purposes a kiln with an output of 25 tons of clinker is a convenient size. The shape of the kiln is a matter that is open to some discussion. It is very evident that in a kiln which is more basin-shaped than cup-shaped, the contents being, so to speak, spread over a greater area, the fire will have less height to travel through before reaching the top, and consequently the kiln will burn off more quickly. A basin-shaped kiln, however, requires a good deal more care in loading than the ordinary bottle shape, for it is very evident that unless it is loaded in exact agreement with the draught, it will not fall in or settle equally when the contents sink during burning, and therefore the calcination will not be carried out equally throughout the kiln. At one works with which the author was connected, there were two 18-ton kilns which were very broad in comparison with their height, in fact basin-shaped kilns, and

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these two could be depended upon to burn off and be ready for loading regularly twice every week. It may be stated here in passing, that after a kiln has burned off, it is a very fair indication of equal calcination if the contents have sunk to a fairly level surface. If there are any parts which are not calcined properly, the contents of the kiln will be "humped up" — to use a burner's phase — at that spot. It will be readily understood that it is of great importance to keep the kilns loaded to their full capacity, i.e. it is very wasteful and extravagant to light up a kiln with a small load, as the same amount of heat has to be expended in heating up the mass of brickwork for a small load as for a large one. Of course, sometimes such a course is unavoidable, as for instance when through an accident the chamber contains a considerable quantity of slurry that is scarcely dry enough to load into the kilns, and it is consequently necessary to light up a small load to complete the drying.

In placing the fire-bars in the kiln, care should be taken that they rest securely upon their supports, as if, by any accident, the bearing bar should become detached, and the bars be allowed to drop just after the kiln has been lit, not only will the proper calcination of the clinker be seriously interfered with, owing to the obstruction of the draught, and the general disarrangement of the loading, but the fire-bars themselves will be utterly destroyed and reduced to a shapeless molten mass by the "firing" of the kiln, i.e. the coke that is placed on the bars to start the fire, as explained on pages 88 and 89. Nor will the difficulty end there, for in drawing the kiln, it will be no easy matter to distinguish and entirely separate the molten metal from the clinker, and if any considerable part of the iron goes forward to the mills, it may seriously damage the grinding machinery. When, however, the fire has got well

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away from the bars, and the kiln is about half burnt off, it is sometimes found desirable to thoroughly shake the bars and draw out one or two here and there, so as to get rid of any dust or ash that may be present, and thus promote a freer draught. This course is more especially found to be advantageous when a kiln is going slowly, and requires infusing with a little more life.

The maintenance and repair of kilns form one of the most serious items of wear and tear in a cement factory. After a comparatively short period, a new fire-brick lining wants continual attention and patching, until it eventually gets unsafe and the kiln has to be relined throughout. The upper part of the lining, which does not come into contact with the white-hot semi-molten clinker, and therefore is not attacked by the lime therein, will be found to last considerably longer than that of the zone of greatest wear mentioned on page 78, and where the kiln is properly back-lined, it is usual, in order to economise fire-bricks, to line this upper portion with bricks on edge only, such a lining being found ample for the purpose of protecting that part of the structure of the kiln. Whatever the wear and tear, it will be found desirable and instructive to keep a record of the life of each kiln lining, and the amount of material and labour expended on it in repairs. In the matter of cost of maintenance, the old original bottle kilns will be found to compare very favourably with the more generally used chamber kilns. Obviously in the former case, there is no long chamber or series of flues to keep in repair, and the lining of the kiln with a chamber attached will be found to give way sooner than that of an open bottle kiln. This peculiarity is doubtless due to the fact that in the latter case, the heat escapes easily without any confinement, whereas in the former, it is more or less confined within the kiln itself, more especially with those types of kiln in which

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the whole of the gases are led direct into comparatively small flues at the side of the kiln.

Joy's patent process, which is a combination of the intermittent and continuous kiln, was once extensively used at certain works in the Medway district. The principle of the process is that the kiln is started with dried slurry and coke in the ordinary way, but when a sufficient body of fire has been thus obtained, wet slurry, mechanically mixed with fine coal or coke breeze, is fed in by hand at the top, according as the fire works up, until the kiln is full of clinker; the fire is then allowed to die out and the kiln drawn in the ordinary way. Attached to the kiln is a small drying floor sufficiently large to dry enough slurry for starting the loading. By means of specially devised machinery, the slurry is delivered alongside the kiln ready mixed with the proper proportion of breeze or fine coal. The manufacturers claim that by this process a complete check can be kept on the burning of the kiln, as the man in charge is always in attendance, and thus a more regular result is obtained than with the ordinary method of burning. Although this system is still used at one large factory, it has been tried elsewhere with varying success and gradually abandoned.

There is no doubt that from an economical and scientific point of view, a continuous kiln is the correct one to use, as in the ordinary intermittent kiln there is an enormous amount of heat wasted, owing to the immense mass of brickwork, etc., to be heated every time the kiln is lit. As one or more men have to get inside the kiln for the purpose of loading, it has to be allowed to cool sufficiently to enable them to work in it, and consequently is nearly cold before it is again lit up.

A type of continuous kiln that has been used in this country with some success is shown in Fig. 18, and was

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patented by Dietsch in 1884. Small coal is the fuel generally used, and the cost of calcination as compared with the ordinary bottle kiln is very small, but, like the bottle kiln, the slurry has first to be dried by separate drying floors, the waste heat not being available for that pur-

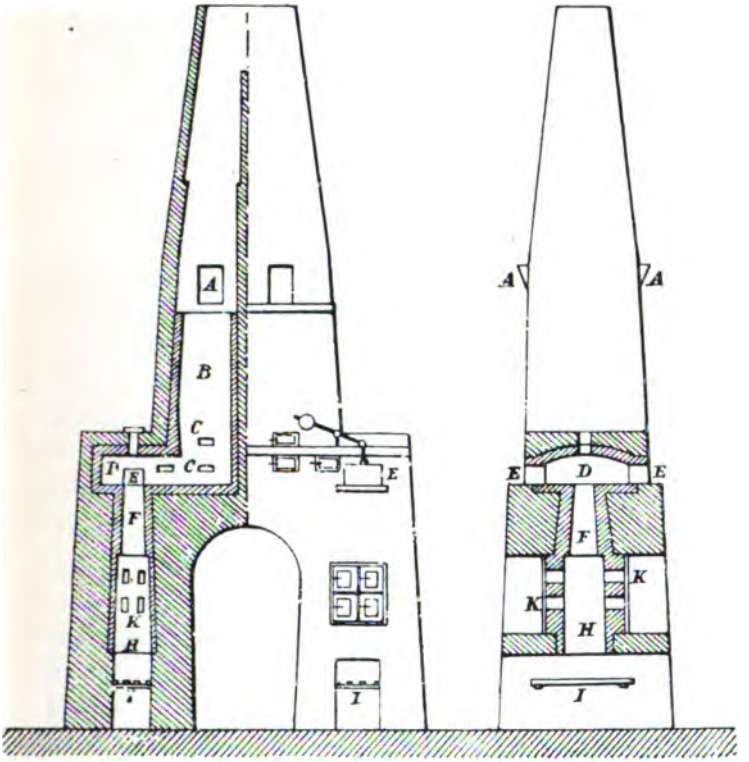

FIG. 18.

pose. The Dietsch kiln may be described as a kiln which does its work by stages, the working part of the kiln being divided into three distinct parts, viz. a heating chamber, a burning chamber, and a cooling chamber. Referring to the illustration, and supposing the kiln to be in full swing,

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the cooling chamber H would be filled with calcined clinker, which is being cooled by the cold air passing through it on its way to the burning chamber F. The cooling chamber thus serves the double purpose of cooling the clinker and heating the air supply to the burning chamber. This chamber is filled with slurry in the course of calcination, as at that point the heat is greatest. The heating chamber B is filled with dry slurry which is fed in at the loading eye A. At fixed intervals, generally about every half hour, a certain portion of the clinker is drawn out at the bottom, which causes the whole mass, both in the calcining and cooling chambers, to sink accordingly ; to take the place of the clinker that is thus removed, a fresh portion of the slurry heated by the escaping gases is raked forward into the calcining chamber, the necessary fuel being added from the eyes E E. It sometimes happens that, owing to the clinker being slightly overburned and vitrifying too much, the mass hangs up, and will not drop properly when a portion is drawn from the bottom ; to overcome this difficulty, eyes are placed at convenient levels at the lower end of the calcining chamber, so that with the aid of iron bars the mass may be detached and again set in motion.

Although this kiln is very economical in its fuel consumption it requires constant attention and charging ; the labour attending its working is very great as compared with the usual type of intermittent kiln, and moreover its working requires very exact and careful attention, the product of course depending upon the skill and care expended upon it by the man in charge. From what the author has seen of this kiln, a large proportion of the slurry is not sufficiently burned ; owing to the nature of the kiln the half-burnt slurry cannot be reburnt in it, and, in order to be utilised at all, has to be reburnt in subsidiary kilns, specially constructed for that purpose. The Dietsch kiln is chiefly used where

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coke cannot be obtained as a fuel, and coal has to be used. Where a good supply of coke is obtainable at a reasonable cost, it will be found more advantageous to use one of the types of intermittent kiln already described, more especially with the wet process of manufacture.

The Hoffman or ring kiln, which is shown in plan and section in Figs. 19 and 20, is not much used in this country for calcining cement, although abroad it has found a certain amount of favour. It consists of a series of chambers arranged in a circle or in a circular form round a central shaft. Each chamber has a flue connecting it with the chimney, and also a loading eye or door opening outwards. The slurry for calcination in this kind of kiln has to be pressed into brick form, to enable it to be properly piled up in the chamber, somewhat similarly to the manner in which bricks are loaded for burning in a brick kiln—in fact, this type of kiln is largely used for brick burning. The principle on which it works is a continuous one. When one compartment is loaded, it is shut off from the succeeding one which is empty and ready for loading, by a sheet of iron or similar contrivance, and the shutter separating it from the preceding compartment just previously loaded is removed. The flue connecting it with the chimney is then opened, and the corresponding flue of the preceding compartment closed. By this means, the waste heat from the compartment which is undergoing calcination, is passed forward through it, and as the compartments are worked in turn, the contents gradually become heated. The cold air, in passing through the previous chambers in which calcination has been completed, is heated thereby before it reaches the compartment containing material undergoing calcination, and thus the cycle continues. It is usual for a compartment to be loaded and one to be drawn every day. The fuel is not loaded in with the bricks, but is fed

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in at the top, through suitable openings, while the contents of the chamber are being calcined. This form of kiln is very economical in fuel, but, like the Dietsch kiln, is very expen-

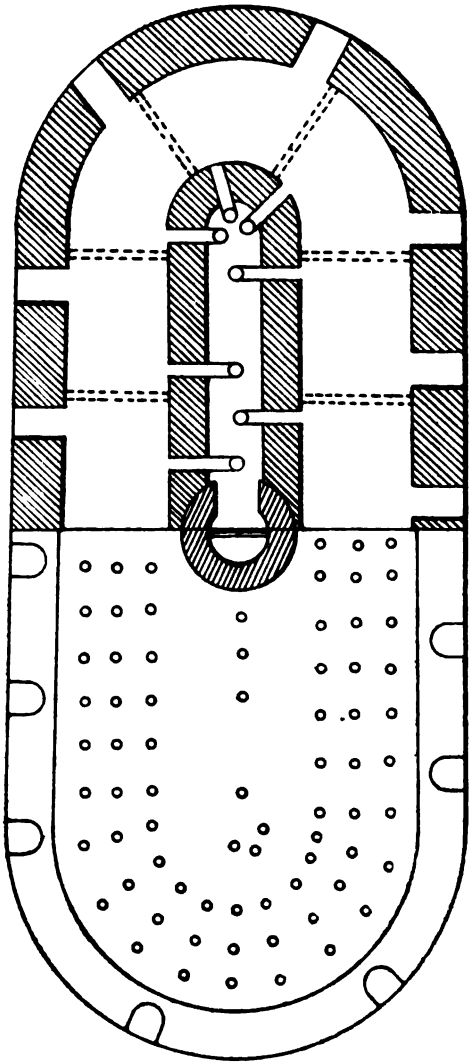

FIG. 19.

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sive in labour, and requires very skilful operation to obtain satisfactory results. The greater part of the cement industry in this country being conducted on the wet system, this type of kiln is not so suitable as some of the intermittent types, but it is used to a considerable extent in Germany, where the dry process is more in vogue. Where the cost of fuel is of more importance than labour, it would doubtless be more economical, but under the conditions of cheap fuel and comparatively dear labour which exist in England, there would be no economy in its use.

A type of continuous vertical shaft kiln, which has recently found considerable favour both in England and

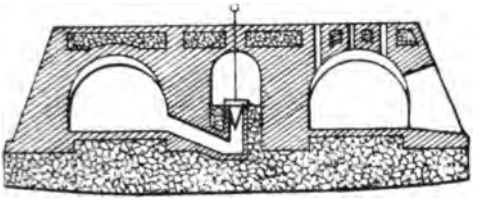

FIG. 20.

abroad, is the Schneider kiln ; but, as the patentees decline to allow any illustration or description of the method of working to be published, very little can be said about it.

The great difficulty with all continuous kilns of the vertical shaft type is, that the clinker is apt to flux and adhere to the fire-brick lining in the clinkering zone, thus preventing the even and regular falling of the load, when the cold clinker is periodically drawn out at the bottom. An ingenious method of meeting this difficulty is that of the Stein patent kiln, an illustration of which is shown in Fig. 21. The kiln consists of a series of cast-iron rings, placed one above the other, so as to form a cylindrical shaft about 8 feet in diameter. These rings are smooth on

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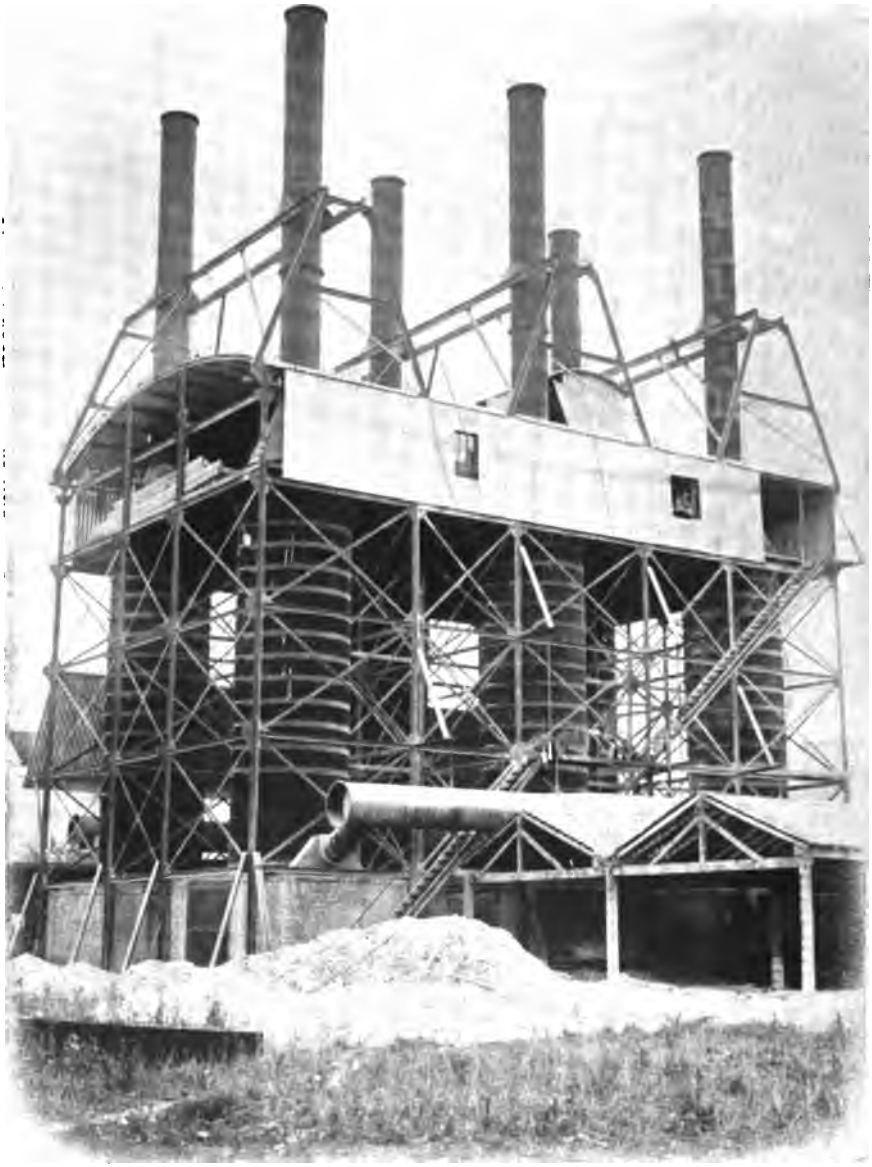

FIG. 21.

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the inside, while the outside is provided with vertical ribs, so that each ring resembles a cast-iron toothed wheel, with abnormally long teeth ; the object of these long teeth is to act as radiators to conduct away the heat, keep the casing cool, and thus prevent the clinker from fusing and adhering to the cast iron. It is claimed that these ribs render it possible for the contents of the kiln to be heated to clinkering temperature without the lining being in any way affected. The author has been afforded an opportunity of inspecting the working of this kiln in the London district, and, from information supplied by the works manager, it performs its duty well and effectually. Where the draught of a tall chimney shaft is not available, these kilns are used with a forced draught ; but, as the patentees point out, the former is preferable, as the draught is more evenly distributed than with the latter.

The latest type of kiln, and one that bids fair to render obsolete all other types, is that known as the rotary kiln. The broad principle of this kiln is an almost horizontal slowly rotating cylinder of boiler plate, lined with fire-brick ; it is not quite horizontal, having a fall of about 1 in 90. At the upper end is fed in the material to be calcined, either in powder or fluid form as the case may be ; at the lower end is injected gas, oil, or powdered coal blast, which supplies the heat. As the kiln rotates the raw material passes slowly down towards the flame. becoming gradually heated in its passage, until it reaches the clinkering zone, where incipient vitrifaction takes place ; and it finally drops out, at the lower end, in rounded granulated fragments of white hot clinker.

This type of kiln was first invented by Mr. Crampton, an English engineer, in 1877, but there is no record of his having put his invention to practical use. Some seven years later Mr. Frederick Ransome further perfected the

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idea, and carried it to a practical issue. The following are the claims set forth in his patent of May 2, 1885 :—

"1. The process of manufacturing Portland and other cement substantially as hereinbefore described, consisting in first reducing the cement material to a dry powder, according to the degree of fineness required in the burnt cement, and then burning such dry powder by keeping it in continuous movement, whilst exposed to the heated products of combustion of a gas or other furnace, so that the cement produced may be used without subsequent grinding.

"2. The process of manufacturing Portland and other cement substantially as hereinbefore described, consisting in first reducing the cement material to a dry powder, according to the degree of fineness required in the burnt cement, and then burning such powder in a slowly revolving chamber heated by the combustion of gas, substantially as described."

One of these kilns, of which an illustration is given in Fig. 22, was given a prolonged trial at a cement works at Grays, Essex, using gaseous fuel, but did not prove a commercial success, and was finally abandoned. It is evident, from the claims in the specification, that Ransome expected to effect great economy in the cost of grinding the clinker by calcining the raw material in a powdered condition ; but he apparently overlooked the fact, that properly calcined white hot clinker is of a semi-molten nature, and would therefore, inevitably ball or clog together in rolling round the cylinder. It may be interesting to note here, as showing how utterly fallacious this idea of economy in pulverisation was, that the chief difficulty with one of the first rotary kiln plants, installed in this country some fifteen years later, was the efficient pulverisation of the resultant clinker ; it being so difficult of reduction, that many of the grinding mills used for intermittent kiln clinker were utterly useless with rotary kiln clinker.

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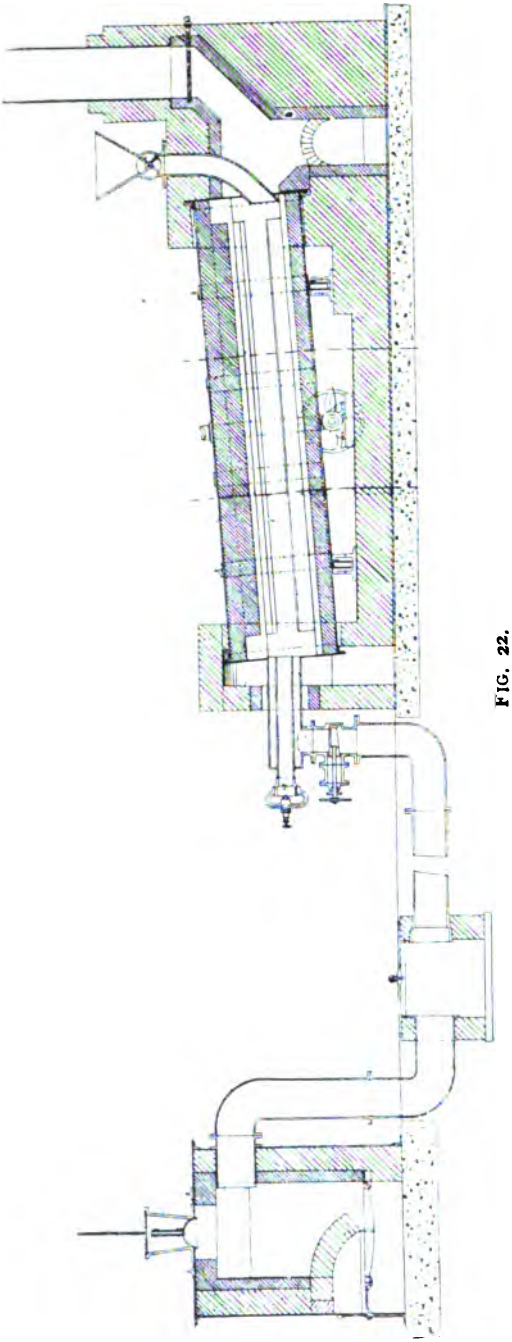

FIG. 22.

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Following Ransome came Stokes' patents of 1886, 1887, and 1888, in which the waste heat from the burning cylinder was utilised to dry the wet slurry on the outside of a specially arranged cylinder, placed between the burning cylinder and the chimney shaft. The hot clinker was also arranged to pass through a cooling cylinder, which served the double purpose of cooling the clinker ready for grinding, and heating the air used for combustion purposes in the burning cylinder. Stokes' patent, though well thought out in many respects, and theoretically economical, does not appear to have gone beyond the laboratory and experimental stages. It was left to our American cousins to follow up and perfect Ransome's and Stokes' ideas, and, after years of patient experiment, to bring them to a practical and remarkably successful issue. Labour in America is, of course, a most expensive item ; and, with the exception of the loading and drawing of kilns, which, by all other intermittent and continuous kilns, is an operation involving considerable manual labour, the whole of the handling of the material in the remaining processes of cement manufacture could be effected by mechanical means. If therefore the defects of the rotary kiln could be overcome, the whole process of manufacture, from the delivery of the raw materials into the reduction mills to the weighing of the finished cement in the warehouse, could be carried through without the material being once touched by hand—an item of no small importance from the American manufacturers' point-of-view ; and it redounds greatly to the credit of American enterprise and energy, that what was abandoned in this country as a hopeless failure in 1886 was, some fifteen years later, reintroduced from across the Atlantic in a modified form as a pronounced success, although it will probably take English manufacturers several years yet to adapt the process in all its minor details to English prac-

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tice. As an instance of the rapid strides the rotary kiln has made in the land of its adoption, it may be said that at least 90 per cent. of the present American output is the product of rotary kilns, and it is very certain that the percentage will continue to increase, for no manufacturer, unless under very exceptional circumstances, would now think of installing the old intermittent or continuous shaft type.

The main broad principle of the rotary kiln, as already described, is the same throughout, but there are countless modifications in the details of the blast, feed of raw materials and of fuel, length and diameter of cylinder, etc. etc., most of which form the subject of patents. Finely powdered coal is now almost universally used, except perhaps in those parts of America where petroleum is cheap, or where natural gas is available. The best coal for the purpose is one which is high in volatile gases and low in fixed carbons; but whatever coal is used, it is necessary that it should be very finely ground, so as to ensure complete and ready combustion. To facilitate grinding, it is necessary that the coal should be thoroughly dried, which is generally effected by passing it through a revolving drying drum, which can be heated with hot air, either from specially constructed furnaces, or with the waste hot gases from the kilns themselves. At one large works in this country the coal is dried by radiated heat from the kiln, an iron casing or jacket being constructed outside the kiln for a portion of its length, so that the coal which is fed in at the upper end, passes down to the lower end as the kiln rotates, and is dried en route, falling out at the bottom into a conveyor, which takes it to the coal-grinding mill. It is hardly necessary to mention that coal dust is a highly inflammable material, and therefore considerable care has to be exercised to avoid explosion, and, with this particular end in view, it is sometimes dried in a revolving drum,

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heated by a steam coil or spiral. Small coal is generally used on account of its cheapness, which is therefore fine enough to be sufficiently dried by either of the foregoing processes; but where large coal is used, it is of course, necessary to crush it fairly fine before drying, which is generally effected by means of one of the types of Blake's crushers shown in Fig. 24, p. 124. The mills generally used for grinding coal are either the Griffin mill, described on p. 144, or the Tube mill, described on p. 156; sometimes a combination of the two is used, the coal being roughly ground in a Griffin mill, and passed through an Askham separator (p. 142), the core or tailings being finally reduced in the Tube mill. As previously stated, the finer the coal is ground the better, but at any rate it should not leave more than 10 per cent. on a No. 100 × 100 sieve. From the grinding mills the pulverised coal is conveyed to hoppers, of convenient size, over the firing end of the rotary kiln, whence it is fed, by specially arranged gear, into the blast tube.

The usual dimensions of the rotary kilns at present installed in this country are from 70 to 90 feet long and about 6 feet external diameter; the latter dimension, after allowing for a 9-inch fire-brick lining, gives an internal diameter of about 4 feet 6 inches. The earlier types of kiln were much shorter, i.e. about 40 feet long, while, on the other hand, one or two instances of longer kilns, up to 100 and even 150 feet in length, have been tried; 70 feet, however, seems to be a usual and convenient size, for it must not be forgotten, that owing to the expansion and more or less distortion of the cylinder, due to heating, it is no easy matter to get a kiln of the above extreme length to rotate readily and freely. It is usual for the kiln to be carried on two or three pairs of roller bearings, fixed at a convenient distance apart according to the length of the

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kiln; to obviate the effect of expansion, as far as possible, instead of the cylinder itself running on these bearings, a flat tyre or collar, 3 or 4 inches larger in diameter, is fastened to it by means of bridges or distance pieces, so that there is free air-space between the tyre and the cylinder. The kiln is generally rotated by means of a toothed wheel, fixed to it in the same manner as the above-mentioned bearing rings, and actuated by a worm wheel geared down to a proper speed from a lay-shaft. In order to be able to control the feed, etc., by varying the speed of rotation, a three-speed gear is usually made use of.

The matter of the fire-brick lining of the kiln and its maintenance, is one of the chief items of expense with the rotary, as with the ordinary intermittent kiln; the semi-molten clinker attacking and more or less fluxing with its acid constituents, being as much a source of trouble in the former as with the latter, and the protective measures adopted are practically the same in both instances. In the intermittent kiln, it is usual to "daub" the clinkering zone with the wet raw cement mixture, while in the rotary kiln, a layer of clinker is induced to form over and adhere to the fire-brick in the clinkering zone, which acts as a protective in the same way. Several kinds of basic fire-bricks, such as Magnesia fire-brick, have been tried with but indifferent success, the friability of the latter proving its chief defect. So far as present experience goes, a highly aluminous brick seems to give the best results; one works with which the author is acquainted use a brick containing about 34 per cent. of alumina with satisfactory results. One advantage which the rotary kiln has over the intermittent kiln, in the matter of repair to lining, is that the clinkering zone can be renewed without endangering the stability of the rest of the lining, whereas

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with the intermittent kiln, the relining of the clinkering zone frequently means pulling down and rebuilding the whole of the lining above. For convenience in attending to lining repairs, etc., it is a convenient arrangement to have the feed and blast arrangement on a movable trolley, which can be run back when the kiln is not in use, and thus allows of ready access to the interior of the kiln.

The matters of fuel feed and air blast are important details, the main desiderata being that they should be regular, reliable, and readily controlled. With some raw materials treated by the dry process, it is found necessary to slightly damp the powder before feeding it into the kiln, otherwise the draught from the blast has a tendency to separate and remove the finer particles; this damping is especially necessary where the mixture consists of a combination of two materials of different gravity, such for instance as limestone and clay, where, but for damping, the draught would separate the two materials, and thus nullify the previous operation of careful mixing and blending. For blast purposes, compressed air from air compressors is the most usual form, but a simple fan blast, with a fan to each kiln, appears to give satisfactory results where used. The rate of feed of raw material into the upper end of the kiln, the rotating speed of the kiln, the amount of fuel consumed, and the force of the blast, should all be capable of regulation from the burner's platform at the lower end of the kiln, so that if the desired amount of calcination is not being attained, it may be regulated by slightly varying the raw material, fuel, rotating speed, or blast. In this respect the clinker from the rotary kiln should be, and if properly managed is, more evenly and regularly burned than that from the intermittent kiln, for the burner has complete control of the calcination process throughout, and can

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readily adjust any little irregularity, whereas with the intermittent kiln, and also with the continuous shaft kiln to a somewhat less extent, a great deal has to be left to chance when once the kiln is loaded.

The clinker as it leaves the rotary kiln is in a white hot condition, ranging in diameter from about an inch to $\frac{1}{8}$ inch, or less, and naturally has to be thoroughly cooled before it can be pulverised. This is generally accomplished in one of two ways: one is to elevate it by a chain elevator to the top of a hollow cylindrical cooling tower, about 30 feet high and 6 feet diameter, from which the cool clinker is drawn from the bottom and the hot clinker fed in at the top; it is thus cooled on its gradual passage downwards, the cooling process being generally assisted by a blast of cool air injected at the base. A more scientific and economical method is to allow the hot clinker to drop into a second slowly rotating iron cylinder, slightly inclined from the horizontal, and fitted internally with a number of longitudinal ribs or shelves of channel or angle iron. These ribs, as the cylinder rotates, carry the clinker up nearly to the top until it falls off to the bottom, to be again carried up, and is thus continuously exposed to the draught of cool air rushing through the cylinder; the air passing through the cylinder being led to the kiln, this arrangement serves the double purpose of cooling the clinker and warming the air supply to the kiln, after the same principle as the Schneider, Dietsch and other continuous shaft kilns. One cooling cylinder, about 45 feet long by 5 feet diameter, will so effectually deal with the clinker from an 80-foot kiln, that it emerges quite cool, and can be easily handled with the bare hand, its temperature probably not exceeding 100° F.

Fig. 23, which is reduced from a working drawing,

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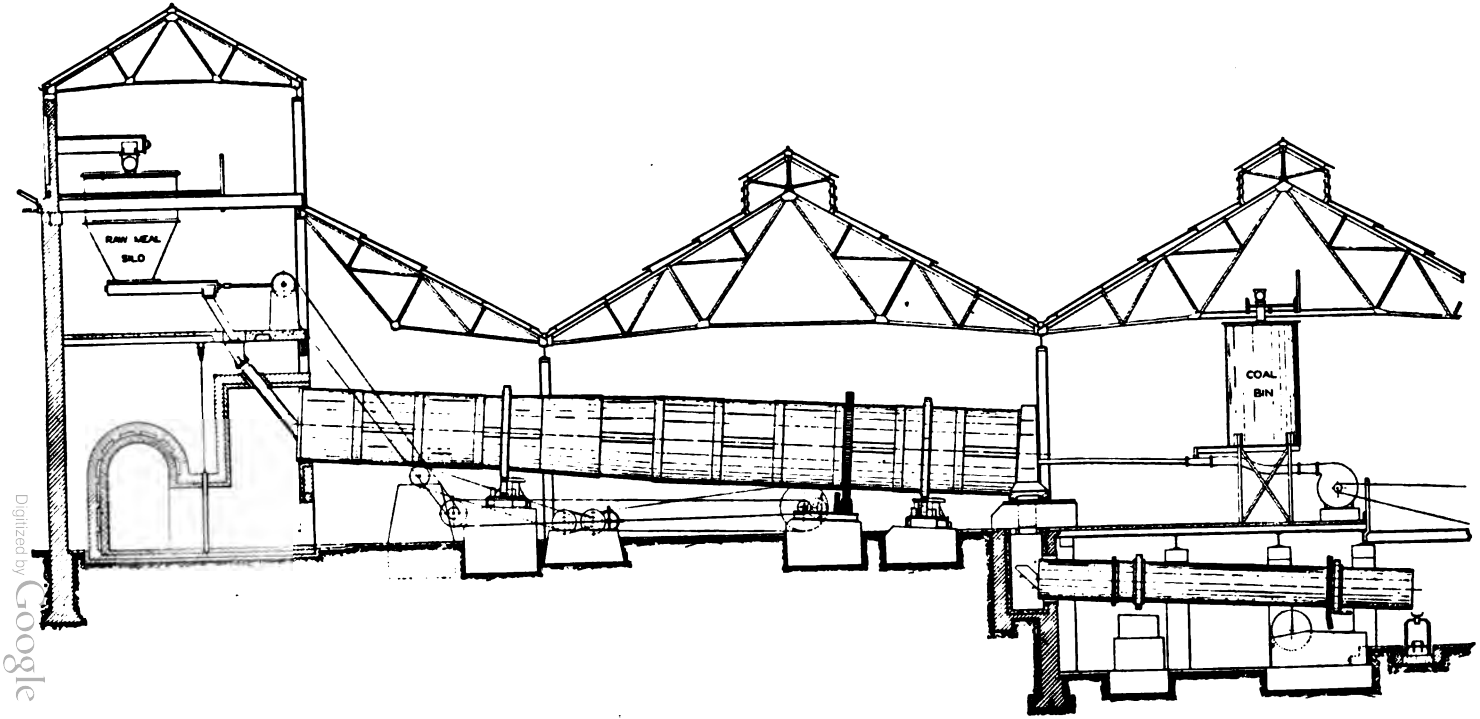

FIG. 23.

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shows the general arrangement of a rotary kiln designed for a dry process plant. The raw mixture, in the form of powder, is brought by conveyors to the hopper over the upper end of the kiln, whence, by specially arranged feeding gear, it is fed forward into the mouth of the kiln. At the lower end the calcined material falls out into a smaller cooling cylinder, whence it is conveyed by tray conveyors to the grinding machinery. The ground coal is delivered into the hopper shown above the fan, whence by specially regulated gear it is fed into the pipe leading from the fan to the firing end of the kiln, and is carried along by the blast to the ignition point.

The matter of efficient grinding of rotary clinker was a matter which for some considerable time severely taxed the resources of the earlier installations in this country, and in the author's opinion there is still considerable room for improvement. Rotary kiln clinker being considerably harder than that produced by ordinary intermittent kilns, it was found that machines which efficiently dealt with the latter, were of no use whatever for the former. Whether it was due to the clinker being overburned, the author is not in a position to state, but the fact remains that many types of ordinary grinding plant were found to be quite useless for the purpose. These difficulties, however, now seem to be largely overcome, and although in some instances the efficient pulverisation of the rotary clinker still leaves something to be desired, the resultant cement is generally equal in cementitious value to that produced from intermittent kilns; with more efficient pulverisation it would probably be far superior. The two methods of pulverisation that seem most in favour are the Griffin mill (p. 144), and the combination of Ball mill with Tube mill (pp. 155 and 156). Instances, however, have come under the author's

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notice in which the Tube mill has been used in combination with the Griffin mill, the latter being used for rough primary reduction only.

One rather uncomfortable property of cement produced by rotary kilns is that it is extremely quick setting, rendering absolutely necessary recourse to artificial methods of regulating the setting, such as the addition of gypsum, watering the clinker, etc. This quick setting property is due to the fact that rotary kiln clinker contains considerably less sulphuric acid in the form of calcium sulphate than that produced by intermittent kilns. The explanation is, that the greater part of the sulphur emanates from the coke or other fuel used, which in the intermittent kiln is volatilised as sodium sulphate in the process of burning, and is subsequently cooled and deposited on the brickwork during its passage through the drying chamber, whence it falls off on to the dry slurry, and is thus brought into the clinker when the slurry is loaded into the kiln. With the rotary kiln, on the contrary, the sulphur compounds are not cooled sufficiently to be deposited until they get outside the kiln, and therefore cannot contaminate the raw material. Of the two methods of regulating the setting, the use of water is decidedly preferable to that of gypsum; for water, even if used in excess, can only be a passive evil, whereas the addition of a more or less foreign material, such as gypsum, may have very undesirable consequences. In any case, whichever agent is used, it should be added automatically in a regular and systematic manner; the too common practice of throwing a shovelful or so of gypsum, or plaster of Paris, on to the top of each wagon-load of clinker, as it goes to the crushers, cannot be too strongly condemned.

With rotary kilns the clinker should be, and if the

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burning is properly conducted, is, all thoroughly and uniformly burned, but occasions sometimes arise when this ideal condition does not always obtain. The clinker being in such small nodules, it is of course practically impossible to eliminate any underburnt fragments by hand picking, and if by any accident they exist in any considerable quantity, it involves the rejection of the whole product. One source of underburned material is that a ring or ridge of clinker sometimes forms, which temporarily dams up the supply of raw material, and when this dam bursts, the material flows to the outlet at such a rapid pace, that it does not remain in the clinkering zone long enough to be properly calcined, and thus a certain amount of underburnt is produced. Another defect, probably arising from insufficient fuel, is that the nodules of clinker are properly burned on the outer surface, but if broken open, the interior is found to consist of yellowish underburned material. This is a most serious defect, for the clinker appears to be of good quality on the outside, and the underburnt material may thus escape detection before it passes to the grinding mills.

Cement produced from rotary clinker is, as a rule, much darker in colour than that from ordinary intermittent kilns, probably owing to more thorough and efficient calcination. Another peculiarity the author has also noticed with several rotary kiln cements, is that the tensile tests at the very early dates, i.e. at three days, are comparatively poor, very often markedly so, while at seven and twenty-eight days, it develops a much higher rate of increase than usual, and consequently equals, if it does not exceed, ordinary cement at those dates. Whether this is due to an inherent quality of the cement itself, or whether it is due to indifferent pulverisation, it is difficult to say with certainty, but the author's experience rather favours the latter view, as he has fre-

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quently found that a short, gritty, badly pulverised cement will develop a higher increase between the dates of testing than one which is finely ground, and all reduced practically to an impalpable powder. The inference is that the grit being less soluble than the powder, it naturally takes the longer to combine with the water, although it eventually becomes active.

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CHAPTER V.

DRY MILLS AND WAREHOUSES.

HAVING in the preceding chapter discussed at considerable length the various methods of calcining the raw material, the next step is to describe the various means of reducing the calcined mass to a fine powder, so as to enable it to readily combine with water. This is one of the most important parts of the manufacture, as it has been proved that the cementitious value of the particle is in strict ratio inversely proportional to its diameter, i.e. the smaller its diameter, the greater its comparative value; apart from this fact, it is very evident that the finer the sample is ground, the greater is its covering power, and therefore the more valuable does it become as a constructive material.

The first step is to draw the clinker from the kilns and convey it to the mill. This, except with rotary continuous kilns, which are usually fitted with mechanical conveyors, is generally done by manual labour, the mass being detached and wheeled in barrows to the crushers; where it has to be carried any distance, it will be found economical to use Decauville wagons or one of the other well-known systems of light tramways.

Where intermittent kilns can be left long enough to cool sufficiently for a boy to enter before drawing, it will be found advantageous to pick off the underburnt portions generally to be found on the surface of the clinker, and

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remove them ready for re-burning. If these underburnt portions are drawn in the ordinary way with the well burnt clinker, they are always crushed up more or less in falling down with the rest of the mass, and are therefore much more difficult to pick out than if removed from the surface in the first instance. Although desirable, this method involves some loss of time, it being more general to commence drawing the kilns before the fire has quite died out on the top of the clinker, provided, of course, that the slurry in the chamber is sufficiently dry to enable such a course to be pursued.

It is impossible to avoid the presence of a small portion of underburnt material in the kiln, and this should be carefully picked out and thrown aside to be re-calcined. Boys are generally employed to pick out this "half-burnt," "pink," or "slack," to give it its various names, as it is thrown up into the wagons or barrows by the drawers. Some firms who recognise the importance of eliminating the underburnt as far as possible, go to the expense of erecting a short length of broad conveyor trays or travelling tables, about 18 inches wide, leading from a hopper to the crushers. The clinker is tipped from the wagons or barrows into the hopper, whence the conveyor carries it forward in a steady stream to the crushers, and a boy is stationed on each side of the table to pick out any underburnt pieces that there may be in the clinker. This arrangement not only affords every facility for thoroughly eliminating every particle of "slack," but also provides a fairly uniform rate of feed to the crushing machinery.

Properly burnt clinker is a dark-green, almost black looking substance, of a spongy, porous, honeycombed nature, somewhat resembling coke in appearance, though of course a great deal heavier and harder. If calcination is carried beyond the point of incipient vitrifaction, the clinker

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loses its porous spongy characteristic, and becomes a dense metallic looking mass, which on grinding is practically inert. Light, very much underburnt clinker, consisting of slurry which has only been subjected to sufficient heat to drive off the carbonic acid, is a soft yellowish substance, somewhat resembling lime—in fact it is nothing more nor less than a species of hydraulic lime. The slurry gets darker and heavier in proportion to the degree of heat to which it has been subjected, until the point of incipient vitrifaction is reached, when it becomes the heavy porous-looking mass above described.

It may be mentioned in passing, that an examination of a piece of underburnt clinker is often of very considerable value in detecting bad or imperfect mechanical mixture of the raw materials. The small pieces of unreduced chalk in the slurry are converted into quicklime, without having been exposed to sufficient heat to make them combine in any way with the rest of the constituents, and they are consequently noticeable in an imperfectly calcined clinker as white, more or less disintegrated particles, showing very clearly what would be the subsequent effect in the finished cement, of small pieces of unreduced chalk or other carbonate of lime in the slurry or compo.

The clinker as it comes from the kilns, with the exception of rotary kiln clinker, which is small enough to go direct to the mills, is generally passed through crushers of the well-known Blake-Marsden type shown in Fig. 24. As will be seen from the illustration, the jaws C^1, C^3 of this machine form a V-shaped opening, the former being stationary, and the latter hinged at E. A knapping motion is imparted to the lower end of the moving jaw by means of the toggle plates, J, K, actuated by the eccentric on the central shaft F; at every revolution of the shaft, the jaw C^3 approaches and recedes from C^1 about half an

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inch; when, therefore, a piece of clinker falls between these jaws, it is crushed by their converging action, and on C^3 receding, it drops still further into the opening to be again crushed, and so the process continues until it is sufficiently reduced to pass out at the bottom. The shaft F is actuated by two heavy fly-wheels, one at each side of the machine, running at about 250 revolutions per minute, so that the crushing power of the jaws is enormous. As the lower ends

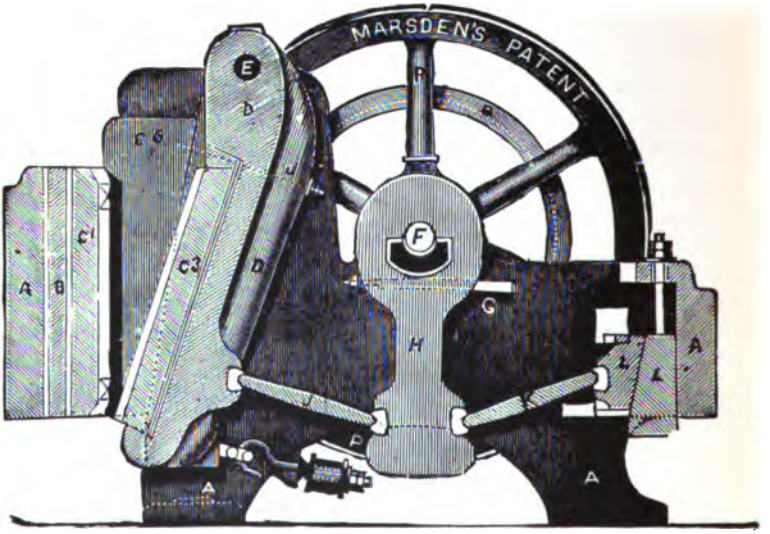

FIG. 24.

of the jaws have the greater part of the work to do, they consequently wear much more quickly than the upper part, and therefore they are made so as to be readily taken out and reversed. It is usual, with this machine, to reduce the clinker to about the size of walnuts; but the fineness to which the material is crushed may be adjusted by means of the screw wedge L, which enlarges or decreases the distance between the jaws as may be required.

A later type of crusher, made by the same firm, is

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shown in Fig. 25, which they describe as their "improved lever motion hand-hammer action" machine. As will be seen from the illustration, the jaws are arranged in the same

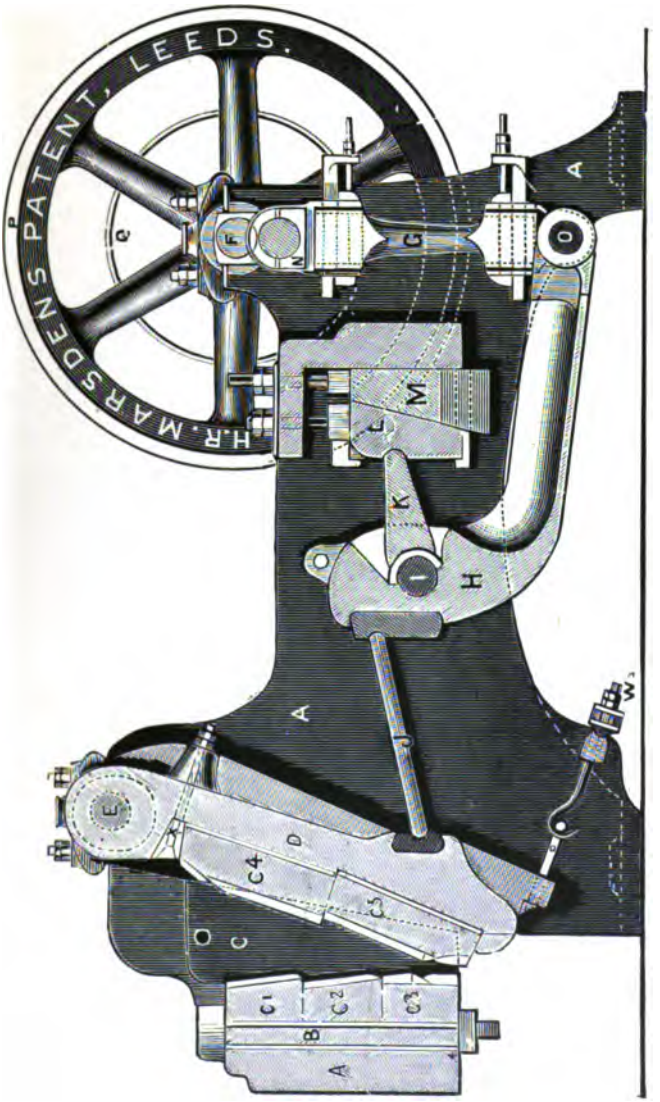

FIG. 25.

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manner, but a lever H is introduced between the pitman G and the toggle plate J. It is not easy to see wherein this motion is an improvement on the older type of crusher, and at first blush it seems rather an unnecessary complication of a very simple machine, though its efficiency is vouched for by more than one well known firm of cement makers.

Although crushers of the Blake type are most generally used for the preliminary reduction of the clinker, some manufacturers employ corrugated or toothed crushing rolls for that purpose. An illustration of a pair of Neate's crushing rolls is shown in Fig. 26. The makers claim for them that the low speed at which they run (5 to 12 revolutions per minute) ensures the minimum of wear and tear, and that when running empty, as crushers often are for a good part of the day, their continuous revolving motion takes much less power to drive than the reciprocating motion of the heavy hammer-like jaw of the Blake type of crusher. Moreover, the curved fang-like design of the teeth of these rolls, tends to crush the clinker finer, or rather to produce more fine particles and dust than the Blake type of crusher, which was originally designed for producing road metal, the essential of which is a maximum of cubical material of a certain size, and a minimum of dust and fine particles.

As the clinker leaves the crusher, or crushing rollers, it falls into the elevator boot beneath, whence it is raised by means of an elevator to the hoppers over the grinding machinery. These elevators are somewhat similar to those already described for elevating the slurry to the wet stones, but as the work they have to perform in elevating rough clinker involves considerably more wear and tear, the buckets are usually attached to a specially designed chain instead of a belt. The hoppers over the grinding machinery may be arranged either as one large hopper to feed two or more

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machines, or a separate hopper may be arranged for each, but in either case they should, in the aggregate, be large enough to contain sufficient clinker to keep the mills going

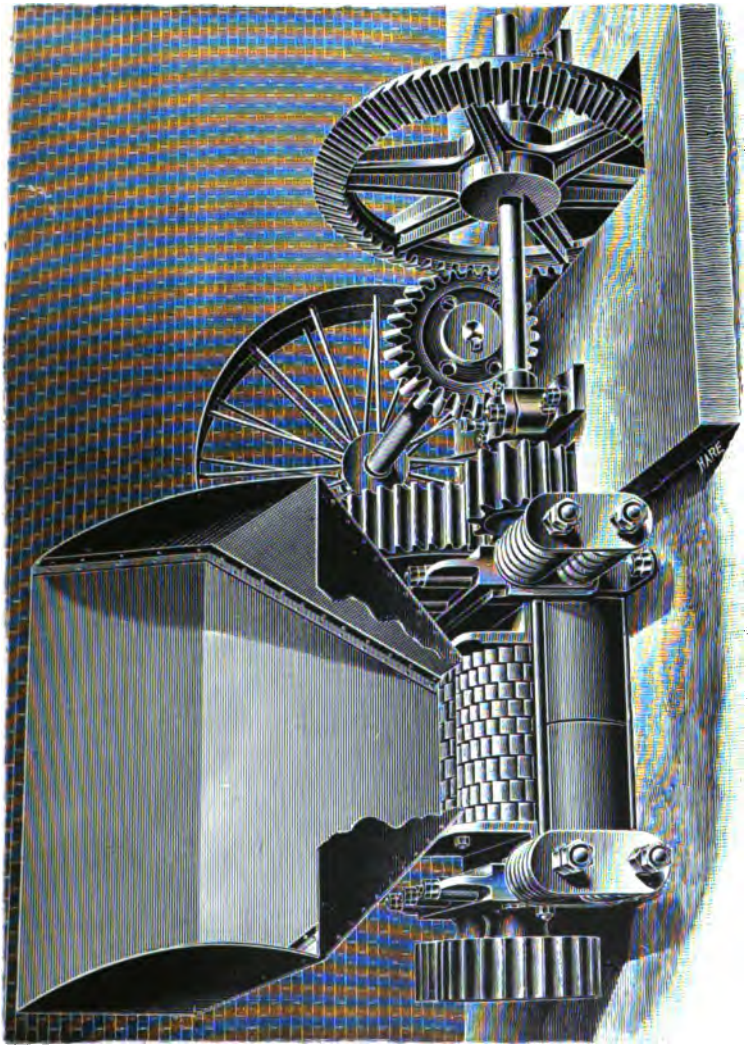

FIG. 26.

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for twelve hours, so that not only would there be a supply in case of breakdown of the crushing and elevating machinery, but as in many works it is the custom to run the mills night and day, sufficient clinker could be drawn during the day to fill up the hopper and leave a supply for the night's working. This arrangement avoids drawing kilns at night-time, which, apart from the inconvenience to the workman, cannot be so readily superintended by the foreman whose duty it is to see that the underburnt portions are properly picked out.

It is usual to place the feeding hopper of the crushers on a level with the ground, so that the clinker can be tipped alongside and gradually fed or "trimmed" in. The practice of tipping wagons or barrows of clinker direct into the crusher is not to be recommended, as it puts a sudden and undue strain upon the machinery; although it costs a trifle more in labour to have the clinker fed in by degrees, it will be found well worth the extra cost in the saving of wear and tear. It is also the duty of the man who trims in or feeds the crusher to keep a bright look out for any scraps of iron that may by accident have got among the clinker, such as small detached pieces of fire-bar or the odd scraps of iron that are sometimes found among the coke. If such pieces of iron should pass the crusher and go forward to the millstones, they shake and damage the grinding face of the latter terribly before they can be got rid of, while some of the patent mills which are in use for cement grinding are very seriously damaged thereby. If by any chance a piece of iron too large to pass through the jaws should be drawn into the Blake crusher, it will be so tightly jammed that the machine will have to be thrown out of work till the toggle plates can be taken out and the obstruction removed. The author has cause to remember one occasion when the workman who was feeding the crusher, was breaking up a large

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piece of burr or heavily burned clinker, and the head of the sledge hammer came off and fell into the crusher, where it became so firmly jammed between the jaws, that a great deal of time and trouble was wasted before the mass could be removed.

The feeding hopper of the crusher being on a level with the ground, the crusher itself is consequently below ground, and arrangements should be made that the pit in which it is placed is sufficiently large to allow of all parts being accessible for lubrication and repairs. As it has rather heavy work to do, it should also be firmly bolted down to a good solid concrete foundation.

The original method of grinding cement was by means of the ordinary 4 feet 6 inch millstones, of the usual bed-stone and runner type, built of specially selected French burrs; although during the past few years millstones have been almost entirely superseded by less expensive methods of grinding, very few of them produce the same amount of flour or impalpable powder as the stones. It is well known that this impalpable powder is the essential feature of the cement, and therefore the comminuting machinery which gives the greatest proportion of flour is the best for the purpose in question.

The millstones used for grinding cement are practically the same as regards gearing as those used for reducing the wet slurry, but the nature of the material to be treated being very much harder and more refractory, the arrangements for feeding and the dress of the stones have to be modified, and the runner is also made much heavier, so as to give greater crushing power. An illustration of an ordinary pair of 4 feet 6 inch stones, reduced from a working drawing, is given in Fig. 27. The feed is effected by a convenient opening in the apex of the overhead hopper, provided with a slide or shutter, whence the clinker drops

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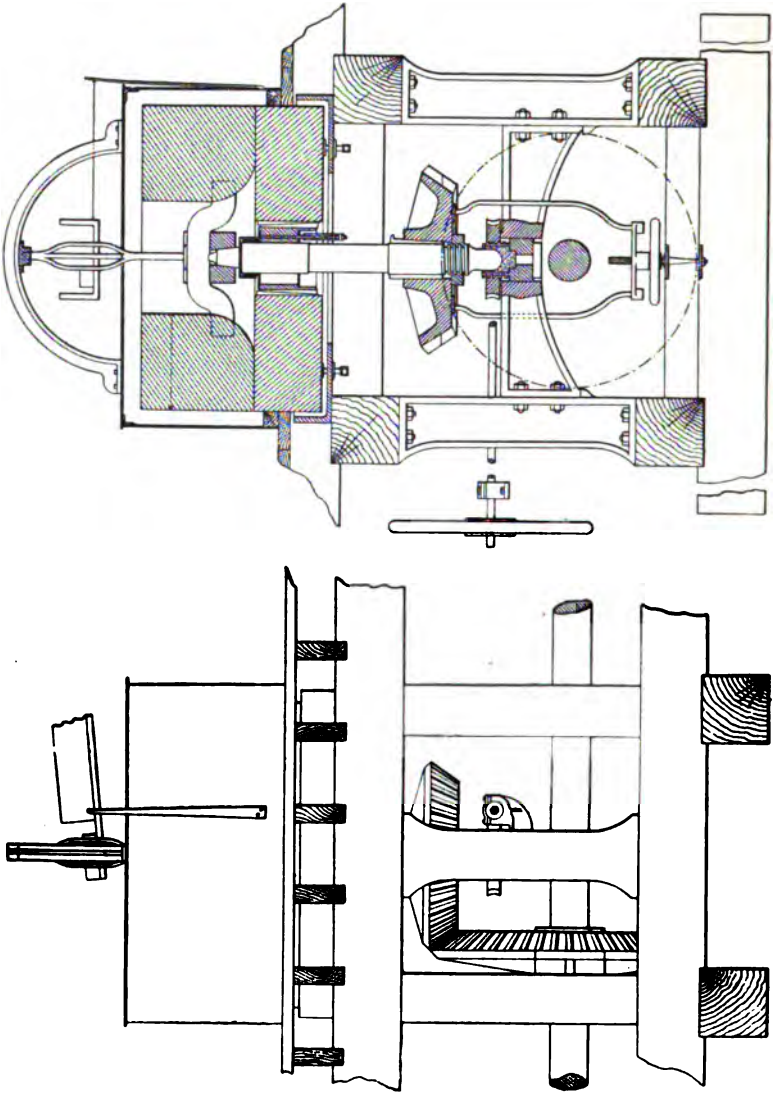
into a small inclined feeding trough or shoe, which leads into the eye of the stone; this shoe is pivoted at the upper



SECTIONAL ELEVATION.

SIDE ELEVATION

FIG. 27.

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end, and at the lower is continually tapped by a revolving "damsel" as it is called, which is attached to the cross-bar, and revolves with the stones. The shoe is kept in contact with the damsel by means of a cord or other attachment fastened to a spring arrangement, generally consisting of a thin wooden wand which is fixed to the outer casing of the stones as shown in the illustration. The amount of shaking, and consequently the feed, depends upon whether the shoe is kept in fairly close contact with the damsel, or whether it is only lightly touched by it. It is important, of course, that the stone should have just as much as it can properly pulverise and no more, an excess of feed resulting in choking the stone, and inefficient reduction. As the grinding face of the runner gradually wears, it is necessary to maintain its weight by "backing"; this is accomplished by fitting two hoops of sheet iron, about 8 inches broad, over the top of the stone, one round its outer circumference and one round the inside of the eye, and filling up the annular space thus formed with concrete composed of some heavy aggregate and Portland cement; lumps of old iron are sometimes added to increase its weight. It will be readily understood that in backing a stone, great care must be taken to afterwards balance it, or it will not run true. The balancing is generally accomplished by leaving three or four cavities at different parts round the outer circumference of the backing, into which molten lead may be afterwards run, until the runner is correctly balanced on the cockhead.

The manner in which the stones are dressed is a matter which varies considerably, almost all works having a method of their own, which they have found by experience to be the best suited to their materials, and have consequently adopted. It is essential, however, in every case that the actual flouring surface of the stones should

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be accurately "staffed" down to a true face. Fig. 28 gives a diagram of three different kinds of dress which, among others, are in use for cement-grinding. The stone illustrated is a runner of the ordinary 4 feet 6 inches diameter; in each case the staffed face is 9 inches wide, and the swallow or throat deepens to 2½ or 3 inches at the eye. No. 1 is the

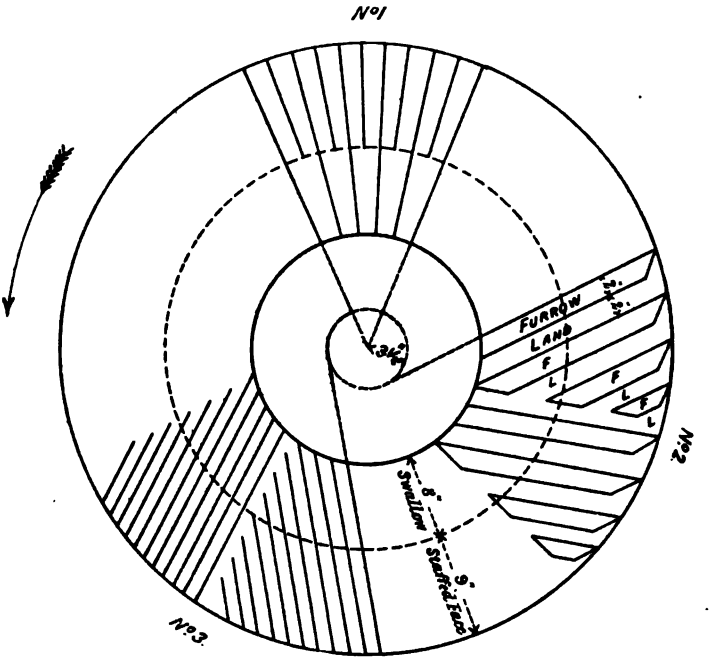

FIG. 28.

simplest of the three, and consists of radial cracks or furrows, each alternate crack being widened towards the centre and carried down the swallow. No. 2 is a rather more complicated form of dress. In this case the furrows are 2 inches wide and about half an inch deep on one side, tapering up to nothing at the "lands" and towards the face of the stone. The "lands," or unfurrowed part of the stone

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are also 2 inches wide, and the lead or direction of the furrow is taken tangentially from a circle 3½ inches behind the centre of the stone, as shown in the diagram. Dress No. 3 is really a combination of Nos. 1 and 2, the lead or direction of the furrow being the same, and the dress itself consisting simply of cracks or narrow furrows ¼ inch deep and about 1½ inch apart.

The dressing of the stones is a very expensive item, both as regards labour, and the consequent wear and tear of the stones, to say nothing of the enforced idleness and unproductiveness of a pair of stones when up for dressing. As a rule, a pair of stones will not run more than thirty-six hours, this period of course depending upon the nature of the clinker under treatment, and the fineness to which it has to be reduced. This means that, with a mill containing four pairs of stones, one pair is always up for dressing. The proper dressing of a pair of stones, and looking after the feed and lubrication of those that are running, constitutes a fair day's work for the miller and his mate. Where the joints of the stone "wash" out, and also where the skirt or outer circumference of the stone breaks away, causing a tendency to throw grit, it is usual to fill up the interstices thus caused by running in molten lead. It is needless to say that the finer the grinding has to be performed, the closer the runner has to be let down on to the bedstone, consequently, the sooner the dress is worn off and the oftener the stones require dressing.

A very convenient method of lifting the runner for dressing purposes, is to support the hopper overhead by means of circular cast-iron pillars, fixed at such a distance from the stones, that by means of a small detachable jib fixed to this pillar, each pair of stones can be reached. Two claws or curved arms attached to a vertical screw running through the end of the jib, grip the

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runner centrally, both vertically and horizontally, in holes in its circumference specially made for that purpose. The claws are lowered sufficiently to be inserted in these holes by turning the handle attached to the top of the screw, and by again turning the reverse way the stone is lifted off the bed and can be swung round on to the dressing platform. The ends of the claws which fit into the holes being circular, and the claws being sufficiently curved for that purpose, the runner can be swung over, face upwards, while in the claws, and thus laid on the platform ready for dressing. This will be found much more convenient than the clumsy method of lifting the runner by means of pulley blocks, and lowering by means of wedges, as the author has seen being done in some mills.

To avoid the constant dressing of stones necessary with ordinary French burrs, Messrs. Addison Potter and Sons, of Newcastle, manufacture a patent combined emery and burr stone, of which the throat only is of burr, the grinding surface, as with their patent wet stones, being composed of rock emery, held in position by a special metallic composition. The author's experience of these stones some few years ago, was that the emery and metal grinding surface had a tendency to wear into concentric rings or grooves, thus rendering it difficult for the ground material to escape, and causing a great deal of unnecessary friction; this was rather a serious objection, as owing to the extreme hardness of the emery and composition, it was impossible to satisfactorily level off the grinding surface to a proper face with ordinary tools. The author understands, however, that stones of this type are now supplied with a narrower face, which take considerably less power than the older form, and give more satisfactory results.

The usual practice is to arrange the millstones on a line shaft coupled direct to the engine, the elevators, sieves and

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other machinery being driven from lay-shafts. As will be seen from the illustration, the stones are driven by powerful bevel gearing direct from the line shaft, the gearing being so arranged that the stones run at about 150 revolutions per minute. It may be mentioned here that, although it is economical so far as first cost of engine, and consumption of fuel and horse-power are concerned, to arrange the whole of the machinery to be driven by one large engine, it is not always economical in actual working, as in case of a break-down in any one part of the machinery, the whole of the works would be stopped until the damage was made good, or until the damaged portion could be disconnected from the rest of the machinery. This often means serious delay and consequent retardation of the output, and it is, therefore, better to subdivide the engine power so as to avoid such a contingency. For instance, in case of a breakdown in the grinding mills, the crushers and elevators also being stopped, the drawing of the kilns would be delayed, and consequently their output retarded, unless the clinker was temporarily stored, which would entail extra expense in again handling to be brought to the crushers. Now, if the crushers and rough clinker elevators were driven by a small subsidiary engine, the drawing of the kilns would not be interrupted by a breakdown of the other machinery, and if plenty of hopper room were provided, the clinker would thus be safely disposed of. Storing clinker in sheds or similar buildings is unsatisfactory at the best of times, as it is always liable to get more or less damaged, to say nothing of the extra cost of twice handling. In the same way, stoppage of the clinker mills would also entail stoppage of the wash-mills, with consequent waste of time and loss of output, and although there are one or two moderate sized works where both wet and dry mills are driven from one large engine, it is more usual to provide separate engine

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power for each. For the reasons previously stated, and from his experience of the serious delays often incurred, the author would go further, and provide a small subsidiary engine for the crushers and rough clinker elevators as above suggested.

As the powder leaves the millstones, it falls into a conveyor, which carries it to the elevator leading to the sieves, which are generally placed at the top of the building. The elevator used for raising the unsifted powder to the sieves is of the usual bucket and belt description, shown in Fig. 29, though, of course, it need not be so heavy as that used for raising clinker. These elevators are generally enclosed in a wooden framing, boarded up as shown in the sketch, so as to confine the dust within them as much as possible, as there is always a small amount of the substance, which in falling out of the buckets, misses the shoot at the top, and drops back down the elevator casing. In a German type of elevator which the author once had under his charge, there was a separate metal casing provided for both up and down buckets, the casing being only just large enough in section to allow of the passage of the belt and buckets. The elevator consequently had to be perfectly vertical, instead of being inclined at a slight angle as is the usual English custom. This arrangement of casing was found to be very awkward in the event of the bucket-belt breaking, as the casing being so small and inaccessible, some considerable difficulty was always experienced in fishing up, for splicing purposes, the broken end, which naturally always fell to the bottom. In the matter of accessibility the English type, with a roomy wooden casing, as shown in the sketch, is much preferable.

From the elevator, the cement falls into a shoot leading to the sieve, which eliminates those particles which are insufficiently ground, the latter returning by convenient shoots

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to the stones to be further reduced, while the fine flour which passes the sieves is conveyed by band or other

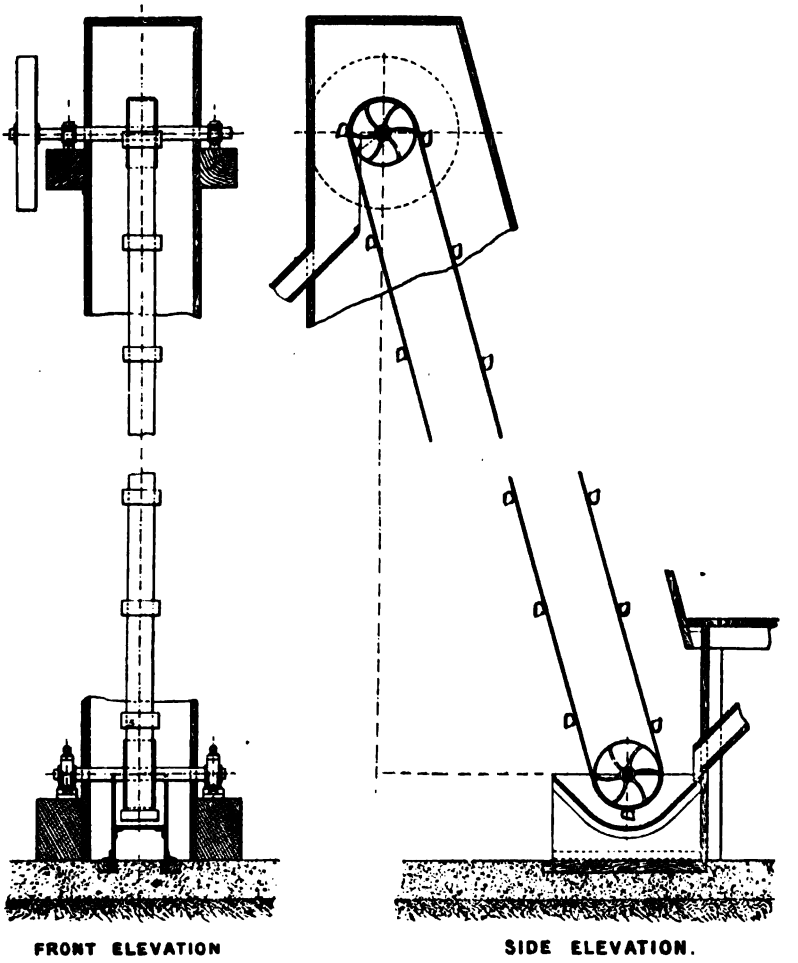

FIG. 29.

conveyors to the warehouse, and by means of suitable openings in the conveyor trough, deposited in the required bin. The conveyors generally used for conveying

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the unsifted cement from the grinding machinery to the sieve elevators, and also for delivering the sifted cement from the sieves to the warehouse, are of the spiral or Archimedean screw type, revolving in a suitable trough. Band conveyors, i.e. a broad band running on rollers, are sometimes used for this purpose, and so far as consumption of horse-power is concerned, are decidedly economical, though they take a good deal more maintaining and keeping in order than the spiral type. For conveying the cement from millstones, or any machine by which its temperature is materially raised, to the sieve elevators, band conveyors are not so suitable, as contact with the hot cement causes them to get out of order very rapidly.

The use of sieves in the manufacture of cement is found to be very economical, as they help the stones considerably, but care must be taken that the proper amount of flouring is done by the stones. It is possible, by excessive sieving, to have a cement which may all pass through a certain sieve, and yet contain little or no flour, it being simply cracked till it is just fine enough to pass that sieve. A practical illustration of this fact—familiar no doubt to many who have tried to make cement in a small experimental way—may be obtained by pounding some clinker in a pestle and mortar with frequent sifting, and comparing the powder thus produced with that of the same clinker emanating from millstones. It will be found that the millstone-ground material contains a much larger proportion of flour than that ground in the mortar, and gives infinitely better results when tested for strength in the ordinary way. There is no doubt that this is just where the many kinds of edge-runner mills now largely used for grinding cement, fail to come up to the old-fashioned mill-stones, viz. in the flouring of the cement. They depend too much on their sieves: the clinker is passed under the runners and all

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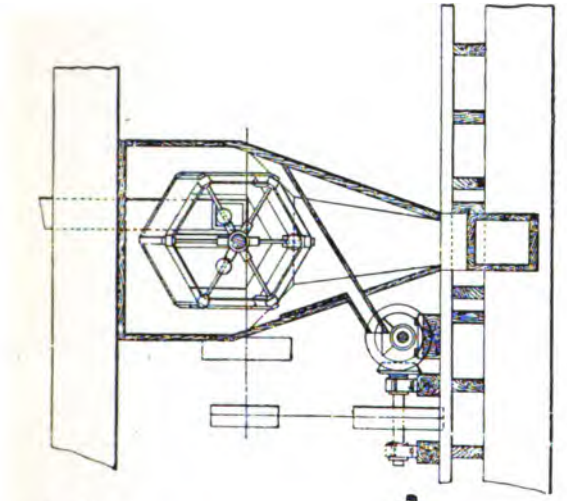
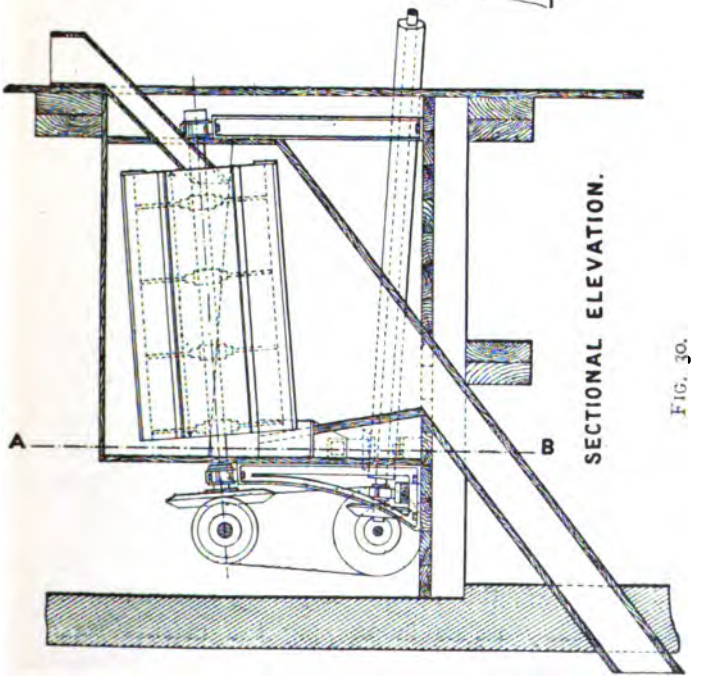
cracked slightly, and then passed up to the sieves; any that is cracked fine enough to pass the sieves is conveyed



SECTION A.B.

FIG. 31.



SECTIONAL ELEVATION.

FIG. 30.

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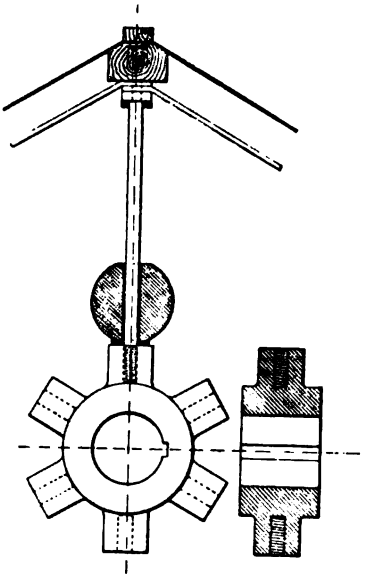
to the warehouse, the remainder being returned to the mills to be cracked again ; so the process continues, the material often passing under the rollers ten to fifteen times altogether before the reduction is completed. So long as the cement will pass the sieves, the promoters of these mills fondly imagine they have done their duty, and lose sight of the fact that it is the impalpable powder or flour which is the essential part of the cement.

The sieves used for sifting cement are of various kinds and shapes, but it will be found that the hexagonal revolving type, as shown in longitudinal and cross section in Figs. 30 and 31, gives very good results. The roughly ground material is fed in at the upper end, and the sieve sloping at a slight angle, it travels slowly towards the lower end, the finer particles passing through the meshes *en route*, so that by the time the bottom is reached, little or nothing but the core or coarse particles remain, and these fall out into a shoot to be returned to the stones. On the arms of the sieve are placed loose sliding balls of cast iron (see detail of hub, Fig. 32), so that as the sieves revolve, these balls fall from the hub to the outer end of the arm and *vice versâ* ; this imparts a jarring action to the sieve, which greatly assists in keeping the meshes clear, and



DETAIL OF HUB.
FIG. 32.

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facilitates the passage of the fine powder through it. To prevent the jar being too severe, a rubber washer is placed at each end of the arm, which softens the fall, and prevents any damage being done by excessive vibration. In some works a square revolving sieve is used of somewhat similar design, and some manufacturers prefer a circular revolving one; of these latter types the author has had no experience, and therefore cannot speak definitely, though he believes such sieves have given satisfaction. For use with edge-runners and similar mills, where a large quantity of coarse particles and fairly large pieces of clinker have to be dealt with, it is usual to arrange two sieves on the one frame, one within the other, the inner one being composed of a perforated steel plate, which retains the coarser and heavier particles, and only allows the moderately fine material to pass to the outer gauze or wire cloth, thereby reducing the wear and tear, and greatly prolonging the life of the latter.

In one works with which the author was connected, a German type of sieve was used, which consisted of a sloping frame about 8 feet long and 1 foot 6 inches wide, hinged at the upper end; two renewable wooden blocks fixed underneath the lower end of this frame, rested on toothed wheels or beaters, similar to a couple of ratchet wheels, revolving on a horizontal shaft, by means of which a jarring motion was given to the frame. The cement was fed in at the top and ran down the surface of the slope, the fine particles which passed through the sieve being conveyed to the warehouse, and the core returned to the stones in the ordinary way. This type of sieve is very convenient, as it can at all times be inspected, and the gauze being fitted into a separate movable frame, the working part of the sieve can be easily removed for cleaning purposes, and if necessary a fresh one put in its place in the meantime. The main objection to these sieves is that the powder has a tendency to converge and run in a thick stream down the

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centre of the slope, by which means the only part of the sieve doing effectual work is the three or four inches in the centre, and unless carefully watched as to feed, the cement is not thoroughly sifted, the core returning to the stones, which should be perfectly clean, containing a large proportion of flour and finer particles.

The Askham Air Separator (Mumford and Moodie's patent) of which a sectional illustration is given in Fig. 33, has lately come into considerable use in cement works, more especially when a very fine cement is required, and consequently the fine gauze of the ordinary sieve is apt to clog and cause trouble. The machine consists of a funnel-shaped casing, within which is a second funnel with an annular space between the two. As its name suggests, the separation is effected by a current of air, which is produced by a fan of special design F F, revolving in the upper or cylindrical part of the casing. The cement is fed into the cone G, and falling on to the rotating disc E, is thrown in a thin stream all round towards the fixed hood D. The current induced by the fan passes upwards and outwards between the fan blades, carrying with it the

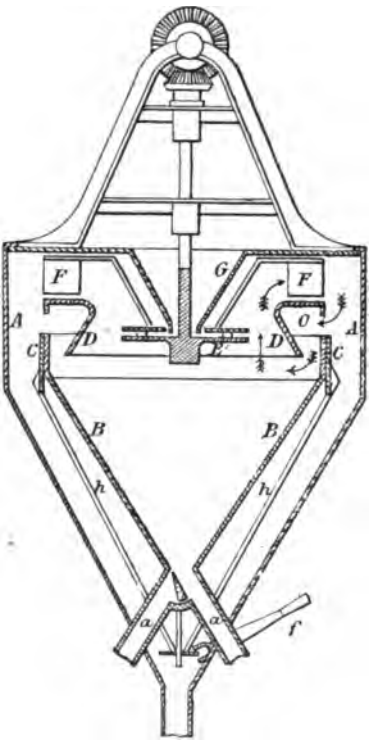

FIG. 33.

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finer particles, which are thrown into the outer casing A and fall out at the bottom for conveyance to the warehouse. The coarse particles, which are too heavy to be lifted by the current of air, fall into the casing B, whence they return by the branch pipes *a a* to the mills for further reduction. The current of air returns through the opening O in the direction of the arrows, the same air being used over and over again. The degree of fineness of the separated material is regulated by the speed at which the fan is made to revolve, and also by the partial closing of the opening O by means of the damper C, which is raised and lowered by the handle *f* actuating the arms *h h*, thus interrupting the current of air.

As has been already stated, there are now many kinds of mills in use for grinding cement, besides the original French burr stones, some machines being used in conjunction with stones, and some performing the entire work themselves. Of the former class, is the Cormorant Mill, patented by Mr. John Hoyle. It consists essentially of a small pair of stones of the usual bedstone and runner type conical in section, and about 24 inches in diameter, the grinding surfaces of which are composed chiefly of specially prepared emery. These stones are driven at an extremely high rate of speed, and deal with the tailings from the ordinary burr stones after the clinker has been run roughly through them, so as to leave, say 40 per cent. of residue on a 50 sieve. The essential feature of the process is the precise manner in which the work is divided between the burr stones and the patent mill. A good deal of cement ground by them has passed through the author's hands in the ordinary course of inspection for shipment purposes, and the grinding has, as a rule, been very fine, in some cases leaving only 3 per cent. on a 100 by 100 sieve. No particulars have been obtainable as to the horse-power con-

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sumed in comparison with other methods of grinding, but the inventor claims a considerable economy.

The Griffin Mill, of which an illustration is given in

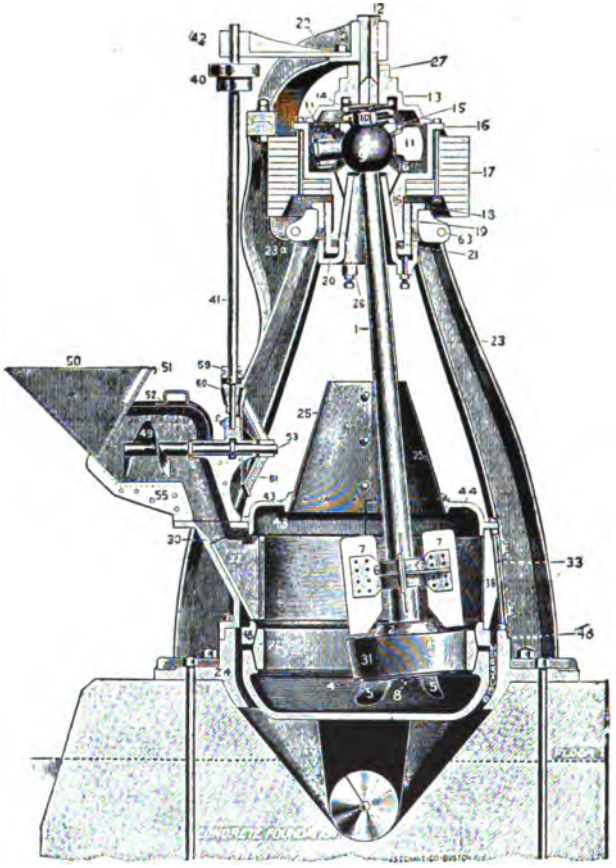

FIG. 34.

Fig. 34, may be used either in conjunction with millstones, i.e. for reducing the tailings or coarser particles rejected by the sieves, after the clinker has passed through the stones, or for performing the entire process of reduction. This

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mill essentially consists of a small crushing roll working by centrifugal force against a ring or die. The crushing roll is rigidly attached to the lower extremity of a shaft suspended vertically from a universal ball-joint, specially arranged within the pulley from which the machine is driven; to this ball-joint are attached trunnions, which work in half boxes, and slide up and down recesses in the pulley head case, so that the crushing roll is free to swing in any direction within the casing. To the bottom of the roll is attached a series of ploughs or stirrers so that when the pan below contains sufficient material to come into contact with these ploughs, it is violently stirred up and thrown between the crushing roll and die. Attached to the shaft above the crushing roll is a fan which assists in keeping the particles in motion and drives them up against the circular sieve or screen arranged above the die. Those particles which are fine enough to pass the sieve drop down through the discharge aperture to the conveyor below, to be conveyed to the warehouse, while the insufficiently reduced particles fall back into the pan at the bottom, to be again stirred up by the plough and passed beneath the crushing roll. The machine is now made in one size only, the diameter of the ring or die being 30 inches, and of the roll 18 inches. The pulley speed is 200 revolutions per minute, by which the makers claim that a pressure of 6000 lbs. is exercised against the die. Should a piece of iron or other unreducible material get into the mill by accident, the crushing roll being free to swing in every direction by means of the special bearing arrangement, would simply pass over the obstruction without causing any damage to the machine. The author has had an opportunity of inspecting several installations of these mills which are successfully working in this country, and judging from testimonial letters, they have also acquired considerable popularity on the continent as

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well as in America, the land of their origin. Their principal success here seems to have been with rotary kiln clinker which is generally more difficult to grind than that produced by the earlier types of kiln, so much so that in many instances the grinding plants ordinarily used for the latter have proved quite inadequate for rotary clinker. With ordinary shaft or bottle kiln clinker, the makers claim an output of from 32 to 40 cwt. per hour ground to a fineness of 3 per cent. on a 76 by 76 sieve, with rotary clinker the average output seems to be from 25 to 28 cwt.

The essential difference between this type of mill and the heavy roller or edge-runner type, is that it is self-contained, the grinding and sieving all being done by the one operation; in the edge-runner mills, on the contrary, the partly comminuted material has to be elevated to separately constructed sieves. In corroboration of the view expressed on page 138 that with edge-runners the clinker is very often only just cracked sufficiently to pass the sieves, without producing the proper amount of flour, the author was assured a short time ago by one firm of manufacturers who had tried mills of the edge-runner type, that they had carefully measured the amount of material passing from them up the elevators, and calculated that for every 2 tons of material that went forward to the warehouse, no less than 50 tons passed over the elevators, indicating that the material passed under the edge-runner as many as twenty-five times altogether; they further stated that the renewals of the gauze of the sieve under these conditions cost no less than 1½*d.* per ton of cement ground, which is not surprising under the circumstances. This was no doubt a very much exaggerated case, the result more likely being due to want of proper feeding and adjustment of the machine, but it is given for what it is worth.

Of the edge-runner or roller type of mill, which performs

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the entire comminuting process, there are several kinds, the original variety used in this country being the Dutrulle and Solomon's edge-runner, followed by Neate's patent Dynamic Grinder, Duffield and Taylor's edge-runner, and Freeman's hydraulic pressure edge-runner. All these mills work on somewhat similar principles, viz. the clinker is passed under heavy rolling discs, which exert a crushing force either by their own weight or by artificial means, and after a certain amount of crushing, is passed out and elevated to the sieves, the insufficiently reduced portions being returned for further treatment.

The Dutrulle and Solomon's edge-runner, of which a sketch is given in Fig. 35, was the earliest mill of this type used for cement grinding. It consists of four heavy rollers or edge-runners about 5 feet in diameter and about 18 inches face, rolling vertically on a circular horizontal path somewhat similar to an ordinary mortar mill, except that the bed or path is stationary and the rollers are made to travel round it. With the Dutrulle mills, the runners are arranged to travel on separate paths, one above the other in concentric terraces or steps; each of the two uppermost rollers has a path to itself, while the work of the lowest path, which is consequently of the largest diameter, is divided between the third and fourth rollers. Clinker is fed on to the uppermost path, and passes downwards and outwards from each terrace and under each roller in turn until it passes over the edge of the outermost terrace, and by means of a scraper arrangement, carried round by the outside rollers, it is brought to the outlet, where it falls into the elevator boot, and is thus conveyed to the sieves. That which is sufficiently crushed to pass the sieves goes forward to the warehouse, the rejected particles passing back to the mills for further reduction. Apart, of course, from the bearings, the main wearing part of these rolls, as with all mills of this

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description, is the surface of the outer circumference which comes into contact with the clinker, and the tyres or rims are therefore composed of specially hard metal and are made detachable so that they can be renewed when required. The main objection to these mills is their cumbersome nature, and the consequent cost of handling for renewals and repairs. Although this type of mill, with certain improve-

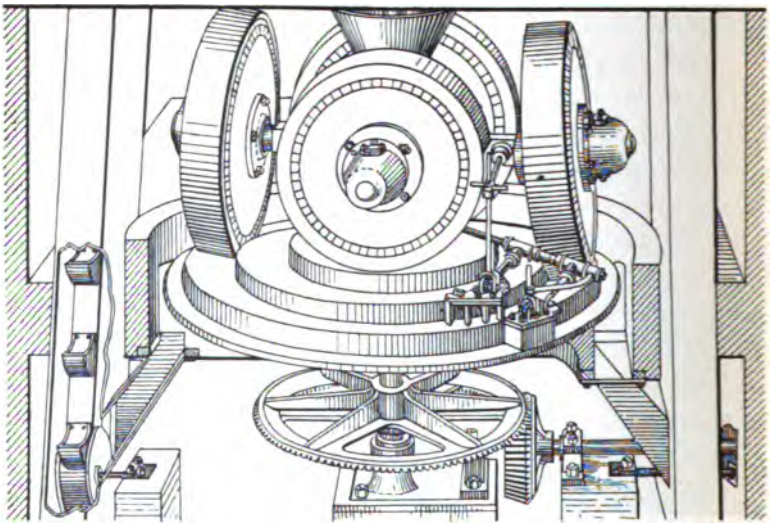

FIG. 35.

ments and modifications, is still working in one or two factories, it is now practically out of date.

Somewhat similar to the Dutrulle mill is Neate's Dynamic Grinder, but with this essential difference, that instead of the roller being vertical, and the path consequently horizontal, both path and roller are tilted inwards at a considerable angle, so that in addition to the crushing weight of the rollers, a certain amount of centrifugal force is exer-

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cised by their outward thrust. In the original mills under this patent, of which an illustration is given in Fig. 36,

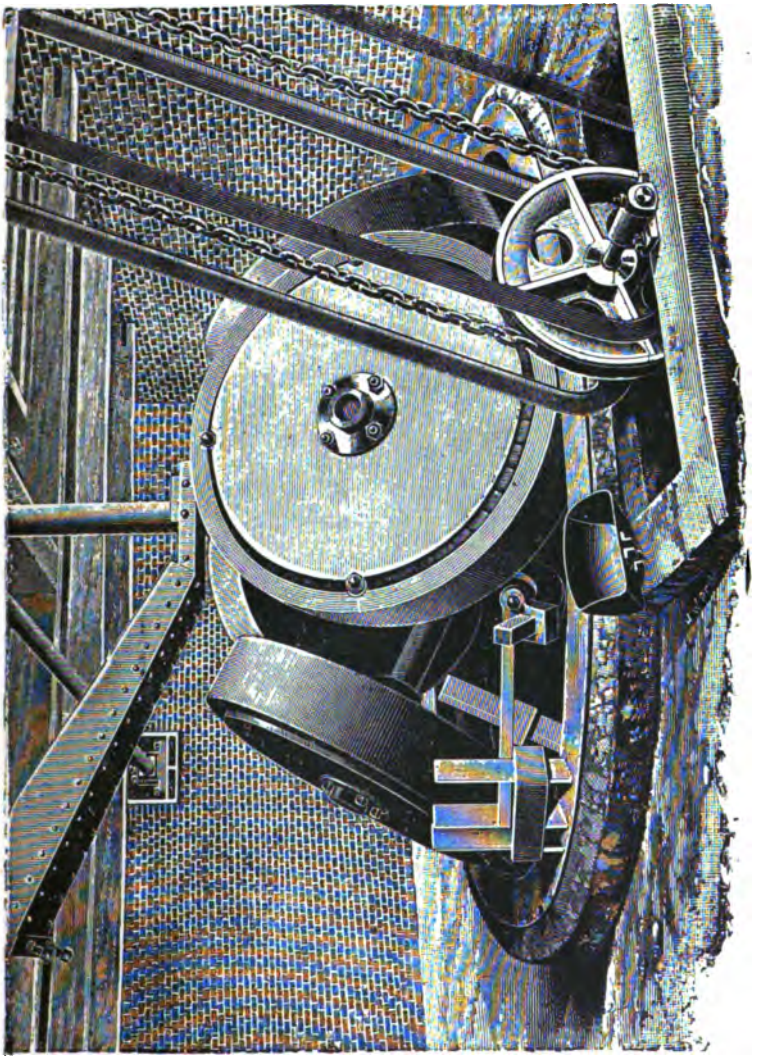

FIG. 36.

there are four rollers of 5 feet diameter, revolving round one path about 2 feet wide by 11 feet outside diameter; in

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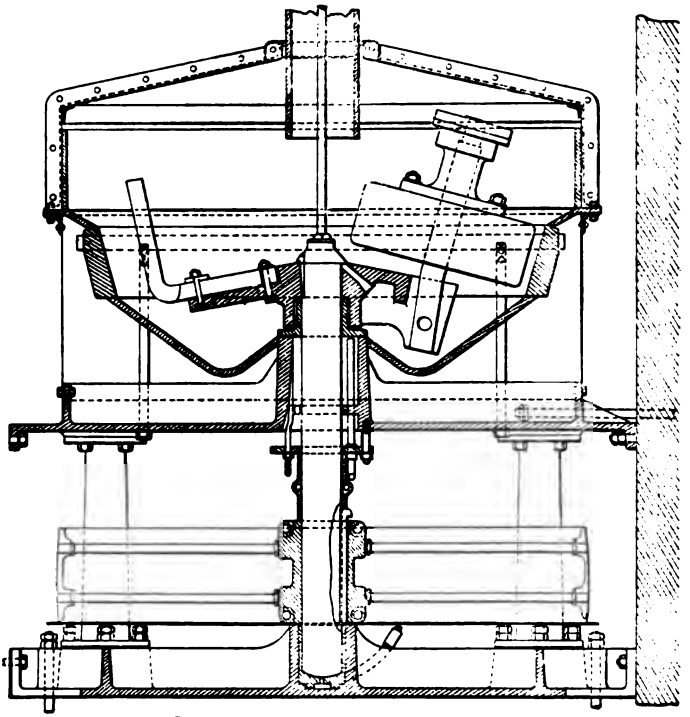
the wake of each roll round the path follows an arrangement of toothed scrapers which, so to speak, harrow up the previously rolled down mass, and present a fresh body of substance to the crushing action of the runners. By a later arrangement, of which a sectional elevation and plan,



SECTIONAL ELEVATION.

FIG. 37.

reduced from a working drawing, are shown in Figs. 37 and 38, these mills are made of a smaller size, viz. with crushing rolls of about 2 feet 6 inches diameter, and a roller path of 5 feet outside diameter so that they can be adapted to the ordinary millstone hurst in the place of French burr stones. These mills, in common with most patent cement-grinding

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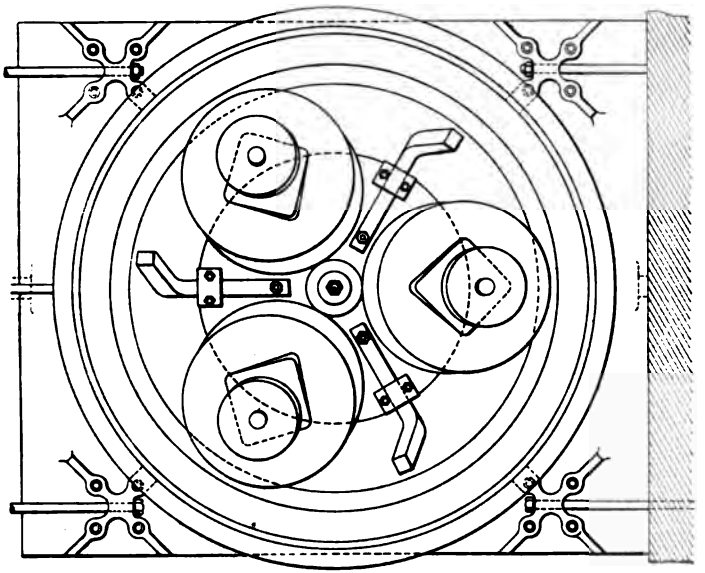
machinery of comparatively recent date, are spoken of favourably by some manufacturers and doubtfully by others, so that it is always a little difficult to form a true opinion of their merits without personal experience. It is only fair to add, however, that they are exclusively used at one small works in which the inventor is interested, and, judging from samples which have from time to time passed through the



PLAN. CASING REMOVED.

FIG. 38.

author's hands for testing purposes, the cement produced by them is certainly ground as well as most cements of English manufacture.

Taylor and Duffield's patent edge-runner mill, of which an illustration is shown in Fig. 39, differs from the usual edge-runner type in that the bed of the mill revolves while the rollers run in specially designed stationary bearings. The essential feature of this mill is that by means of a cam

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action on the driving shaft, the runners are made to work to and fro laterally, by which it is claimed that a crushing power, more nearly resembling millstones, is imparted to them. This mill is made in two sizes, the large size for

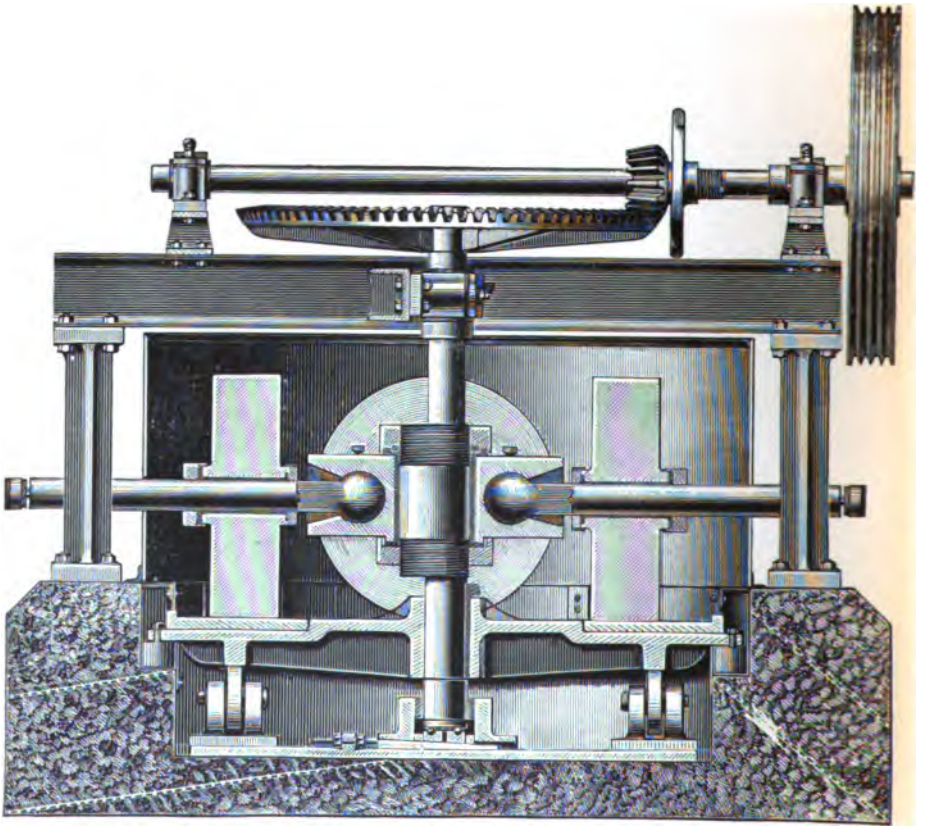

FIG. 39.

separate erection and the smaller size to fit an ordinary mill hurst in the place of millstones.

A type of edge-runner which seems to have gained considerable favour among manufacturers in the Thames and

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Medway district is Freeman's patent hydraulic pressure grinder, manufactured by Messrs. Aveling and Porter, in which small diameter rolls are used, and pressure is supplied to them by hydraulic means. An illustration of a pair of

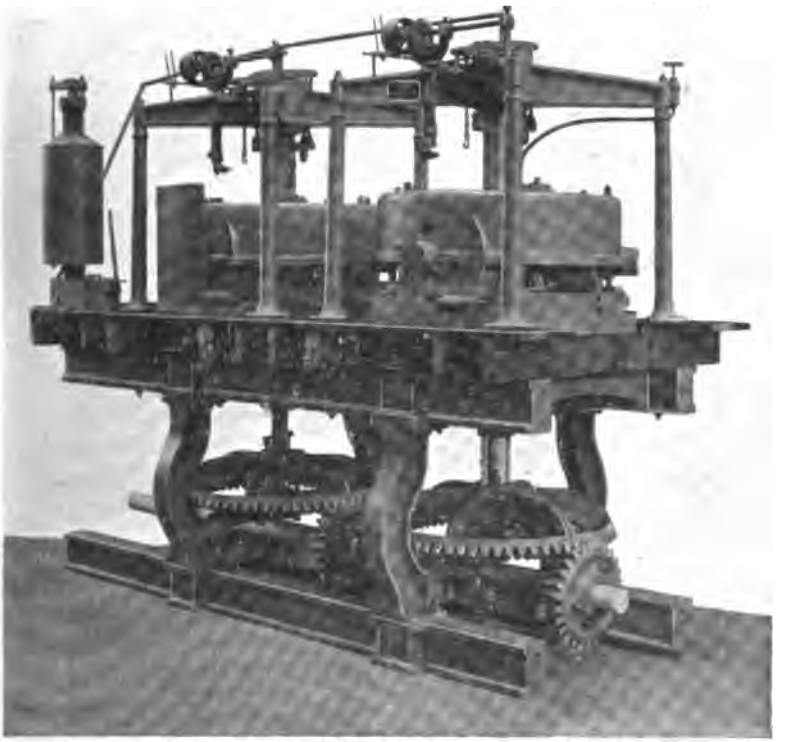

FIG. 40.

these mills, reproduced from a photograph, is shown in Fig. 40. There are three rollers about 2 feet in diameter and 10 inches wide, carried in a massive cast-iron revolving frame, the whole revolving on a chilled cast-iron bed-plate. A hy-

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draulic ram is arranged at the top of the machine, and the pressure is supplied from a small pump and accumulator fixed at any convenient position in the building. By means of this pump and accumulator, any desired pressure may be put upon the rolls according to the hardness of the clinker to be reduced, or they may be allowed to run with their own weight only, without any extra pressure being applied. In connection with the revolving frame are ploughs and clearing irons, so arranged as to keep the clinker under treatment continually in motion, and ejecting the ground material through an outlet provided for that purpose, for conveyance to the sieves in the ordinary way. This machine is driven from below in the same manner as millstones, and is so arranged that it can be readily placed on an ordinary millstone hurst in lieu of stones. As with all mills of this description, the chief wearing parts are the rims or tires of the rolls, and, judging from personal observation, the hardness of the metal of which these rims are composed seems to vary a good deal. Unless the metal is specially good, hollow and uneven places quickly make their appearance in the surface of the rims, with a corresponding diminution of efficiency. The same remark as to the varying quality of the metal applies to the path upon which they travel, and it seems that in this direction it would pay the manufacturers of such machinery to employ a metallurgist to discover why some of their rims wear so much faster than others, although all are supposed to be composed of the same metal.

The cylindrical ball mill, shown in longitudinal and cross section in Figs. 41 and 42, is a type of mill which in one or other of its various modifications, promises to become a standard method of pulverisation, either for use by itself, or as a means of primary reduction for use with the tube mill described later on. As will be seen from the illustra-

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tions, it consists of a revolving cylindrical chamber, divided up into segments with inclined steps. Rolling round the cylinder as it revolves, are a number of balls of various sizes,

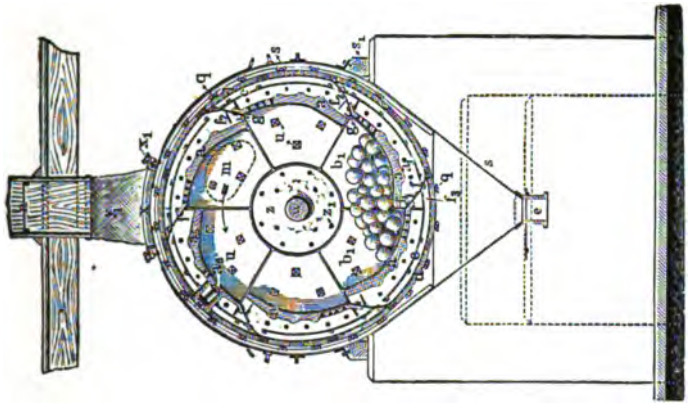

FIG. 42.

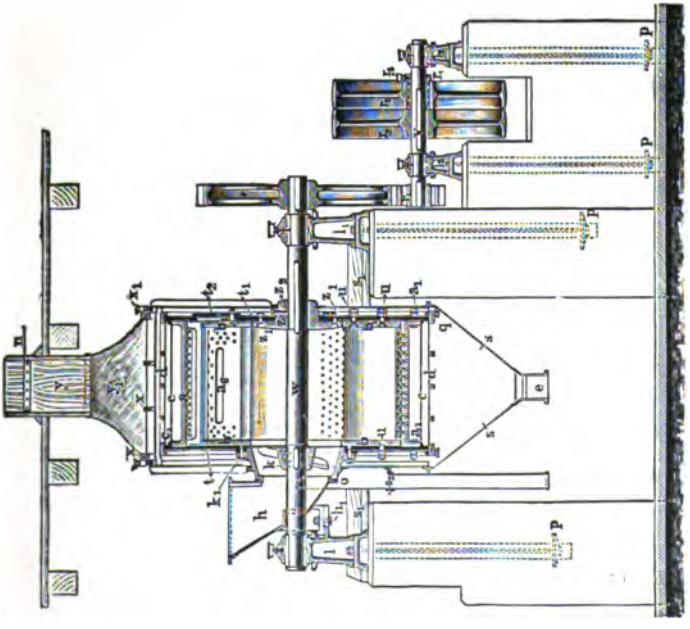

FIG. 41.

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between which the clinker is crushed and pulverised, and their crushing and disintegrating power is further increased by their continual falling over the steps as shown. The path on which these balls travel is composed of specially prepared hard metal, and is perforated, so that when the clinker is sufficiently reduced, it passes through the perforation and falls first on to a perforated steel plate, which removes the coarser grit, and thence again on to a wire gauze of finer mesh. The powder which passes the gauze, falls out and is conveyed to the warehouse in the usual way, and

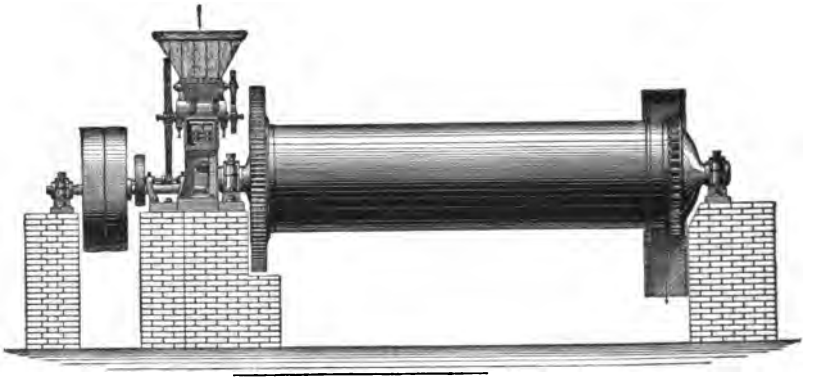

FIG. 43.

the grit retained by the perforated plate and the sieve is automatically returned to the interior of the cylinder for further reduction.

A method of completing the pulverisation of the clinker, which has lately made considerable headway, is that known as the tube finishing mill, an illustration of which is given in Fig. 43. It consists of an iron cylinder about 15 feet long and 4 feet in diameter, about half filled with flints or other hard pebbles. This mill is only intended for completing the pulverisation of the cement, and all the material fed into it has to be first reduced by some other means, so

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as to all pass through a sieve having about 20 holes per lineal inch. The cylinder is perfectly horizontal, and is caused to rotate at about 25 to 30 revolutions per minute. The coarse grit is fed in at one end by an automatic arrangement, and a steady feed being thus maintained, it gradually finds its way by gravitation to the outlet at the other end, being pulverised and reduced in its passage by the crushing action of the flints falling upon one another during the rotation of the cylinder. The lining of the cylinder is composed either of renewable cast-iron strips, or of a small specially prepared brick, somewhat resembling porcelain, set in a sort of cement also specially prepared for the purpose. These mills may be used in conjunction with millstones, or with any other machinery that will first roughly reduce the clinker to the fineness above mentioned, i.e. so as to pass a 20 sieve. As an auxiliary to an already existing millstone plant, they are especially valuable, as they relieve the stones of the most trying and expensive part of their duty, i.e. the final reduction and flouring of the cement. It will be readily understood that when they only have to roughly reduce the material, the stones may be allowed to run comparatively light, and therefore do not require such frequent dressing, their useful life being consequently greatly prolonged. The output of a tube mill naturally depends upon the ultimate fineness to which it is required to reduce the cement, and also upon the coarseness of the rough grit fed into it, it being possible by reducing the feed to attain almost any degree of extreme fineness. The following are two examples kindly furnished by the manager of a cement works where these mills are in use, showing the fineness of material entering and leaving the tube mill, and the output per hour :—

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		Residue on sieves having — holes per lineal inch.				
		180	100	76	50	Output.
		p.c.	p.c.	p.c.	p.c.	
No. 1	Material entering mill	47	38	34	28	2¾ tons per hour.
	„ leaving „	23	12	6	1	
No. 2	Material entering mill	72	67	62	56	4¼ tons per hour.
	„ leaving „	37	24	16	6	

Where these mills are not required as an auxiliary to an existing millstone plant, it is obvious that some method of preliminary reduction which does not require such constant dressing and attention might be very advantageously substituted for the millstones. Many firms of manufacturers have adopted tube mills as a finishing plant, in conjunction with the ball mills described on page 155, and as both are automatic and extremely simple in their method of working, the cost of attendance is but trifling, while the cost of maintenance compares very favourably with that of other methods.

The economical and efficient pulverisation of cement is a matter which has been exercising the mind of the English cement manufacturer, for some time past, and all sorts of inventions have been brought forward for that purpose, some of which still survive, but the greater number have been gradually abandoned. The mills previously described are those which have found most favour in this country, but without making any invidious distinction, it is doubtful if any of them produce the same percentage of flour, or impalpable powder, as the ordinary French burrs with the exception perhaps of the tube mills. As has been already stated, it is possible for two samples ground by different machines to give the same result on a 50 sieve or on those usually used for testing, and yet one may be all fine grit and the other chiefly flour. In the course of a public discussion on the subject a few years ago

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a patentee and manufacturer of one of the most extensively used edge-runner mills at the present time, admitted the approximate accuracy of the author's statements, viz. that a cement ground entirely by millstones, and leaving about 10 per cent. residue on a 50 sieve, was equal in cementitious value to one ground by edge-runners and leaving only 6 per cent. A few weeks later a patentee and manufacturer of a rather different type of edge-runner mill challenged this statement in the press. Unfortunately for him he had written to the same journal a month or two previously, giving the comparative results of tests of the same cement ground by his own mills and French burr stones, which showed that although the former was ground so as to leave only a trace of residue on a 50 sieve, it carried 15 lbs. less at 28 days when mixed with three parts of standard sand than the latter, which was ground to a fineness of 4 per cent. on a 50.

As regards the power required by the various types of mills, the late Henry Faija in his paper on Portland Cement prepared for the Columbian Exhibition at Chicago in 1893, gives the following comparison:—

"The power consumed by the several principles, reduced to the proportion of 1 ton of cement per hour, may be approximately stated to be as follows:—

For millstones .	. 30 to 32	I.H.P. per ton per hour.
Ball principle .	. 16 „ 18	„ „
Edge-runner principle	12 „ 14	„ „

in each case the cement ground to a fineness of about 5 per cent. residue on a 50 by 50 sieve, and it will thus be seen that the power required is proportionate to the amount of flour produced."

It has been sometimes stated that the general superiority in cementitious value of cement ground by millstones over that ground by edge-runner and similar mills,

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is due to difference in the shape of the grain produced by the different methods, the millstones being supposed to produce an angular jagged grain, and the edge-runner a rounded one; and that the former consequently interlocks better, and forms a more tenacious matrix than the latter. With this view the author cannot agree; he has examined many samples microscopically, and can find but little difference in the shape of the grains produced by the various methods of grinding, at all events not sufficient to account

FIG. 44.

for the superiority of the one over the other. Fig. 44 is a micro-photograph of the grains produced by millstones, and Fig. 45 of those produced by edge-runner mills. The grains in each case are those which have passed through a 76 × 76 sieve, and have been retained on a 100 × 100, and are consequently magnified about 30 diameters, and it will be seen that in shape they are exactly alike. As already stated, the superiority of the millstone cement is rather to be attributed to its containing a greater proportion of

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impalpable powder or flour. When cement clinker is reduced to an absolutely pulverulent condition, it is no longer black and opaque, as it appears in the grains retained by an ordinary testing sieve, but splits up into transparent crystalline fragments. If the finest particles of cement flour are examined under the microscope with a fairly high power, say a $\frac{1}{4}''$ objective, it will be found that they have a transparent crystalline appearance, very much like white moist sugar ; these fine particles are the essential and most

FIG. 45.

active part of the cement, and so long as the sample contains its due proportion of them, it is obviously immaterial whether this degree of fineness is produced by millstones, edge-runners, or any other method of grinding.

The author, however, is very strongly of opinion that in using French burrs, the tendency has hitherto been to make them do more than their fair share of work, i.e. they have been required to both crush and pulverise the clinker ; instances have come under his notice in which clinker has

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been fed into the stone hopper, in pieces 2 or 3 inches in diameter, instead of being of the size of walnuts. If instead of putting so much work on the stones, a more gradual method of reduction were adopted, the results would amply justify the outlay—in fact, one case came under his notice in which the clinker, after passing the usual Blake's crusher, was passed through a pair of powerful rolls of continental manufacture, which further reduced it, so that none of the material fed into the eye of the stone was larger than a hazel nut. The output of the stones was thereby enormously increased, and the extra power absorbed comparatively small.

The arrangement of the warehouses for storing the cement after grinding, is a matter which rarely receives the attention it deserves, the general plan being to make any kind of building serve the purpose, without due regard to the necessities of the case. A separate warehouse should be allotted to each set of mills, and proper provision made for dividing up each one into suitable bins, so that if from any cause the contents of a certain kiln should not prove quite satisfactory (and accidents will sometimes happen), the doubtful material can be ground into a separate bin, and kept distinct from the rest of the manufacture.

A very convenient plan of arranging a warehouse where the product has to be disposed of by rail, is to have a long building with a division longitudinally down the centre, and each side divided off into bins of 100 or 200 tons capacity according to requirements. A railway siding being arranged alongside the whole length of each side of the building, trucks can be loaded with great facility from any given bin. The front of each bin may be composed of stout wooden planks fitting into a groove formed by two battens nailed on to the vertical supporting timber of the building, so that when it is required to empty a bin, it is only necessary to pull out these planks, and the mass falls out ready

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for packing. With such an arrangement of warehouse, the conveyor is generally carried in the timbers of the roof, and the cement coming from the mills can thus be delivered at any required spot.

Although, theoretically, cement ought to be fit for use immediately after grinding, it has always been found in practice that it greatly improves with age, and therefore it should never be sent out freshly ground when such a course can be avoided. Apart from the risk attending the use of such fresh cement, the general experience is, that to put hot, freshly ground cement into sacks greatly affects the durability of the latter, and tends to make them rotten long before they would have been in the ordinary way with cool cement. The ideas which some manufacturers of cement-grinding plant have of the storage requirements of a cement factory are rather amusing; the author well remembers one case in which the plans of a factory, designed by such a firm, were submitted to him for inspection; the cement, after leaving the sieves, was allowed to fall into a small hopper of two or three tons capacity, whence it was led direct into the sacks by a sleeve arrangement, such as is usually seen in a flour mill.

In addition to maturing the cement before delivery, another advantage, by no means inconsiderable, of having plenty of warehouse room, is that, during the winter months or when trade is temporarily slack, the works may be kept going at their full capacity, and thus the working expense kept down, for it is unnecessary to remark that the greater the output, the less the cost per ton for salaries and establishment expenses. A short output is unsatisfactory both to master and man: to the former because of the increased cost per ton, and consequent loss of profit, and to the latter because he is on short time, and only earns part of his proper week's wage.

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CHAPTER VI.

DRY PROCESS.

THE "dry process" of cement manufacture, as it is termed, has to be adopted where the physical properties of one or both of the raw materials to be used, are of such a hard nature that they cannot be mechanically mixed and blended in the wash-mill with water, and, as the name suggests, have to be ground and mixed in a dry state. The process may be briefly outlined as follows. The materials are first dried if necessary, ground to powder and mixed in their proper proportions, damped slightly, pressed into bricks, and then again dried before being loaded into the kilns for calcination; the subsequent operations of crushing and grinding the clinker being the same as in the wet process. The principal materials treated by this process are the limestones and shales of the Lias formations of Warwickshire, and the limestones and clays of Wales and elsewhere; the soft chalk marls of Cambridgeshire have also been recently successfully treated by the dry process.

Where clays and similar wet silicates are used, it is obviously necessary to first dry them thoroughly before they can be ground to powder, and for that purpose drying floors, or other means of removing the moisture, have to be employed. Even when the materials are apparently dry, such as limestones and shales, and appear to grind satisfactorily, it is found economical to dry them more thoroughly by artificial means before grinding, since when quite dry,

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there is no tendency to clog, and the increased output of the mills more than compensates for the cost of drying. Drying floors are generally heated by furnaces or ovens of the type described on page 76, although in some cases floors heated by the exhaust steam from the engine are made use of. An illustration of one of these steam-heated floors is given in Fig. 46. The illustration is reduced from a working drawing, and shows the drying floors in plan, longitudinal and cross sections. It will be seen that the floors are constructed in a somewhat similar manner to those heated by ovens, and are covered by iron plates. The steam pipes traverse about half the length of every third flue, and the walls of the flues are built of perforated brick-work, so as to allow the steam to circulate freely beneath the whole surface of the floors.

Another method of drying raw materials for treatment by the dry process, which appears to be gaining considerable favour, is by passing them in a roughly ground condition through a hot, slowly rotating drum or cylinder; these rotary dryers, as they are called, are usually heated by means of a coke furnace, the hot gases passing through the interior of the cylinder and also round the outside of it.

The materials being in a properly dry condition, the next step is to grind and mix them; and, as in the wet process, the quality of the resulting cement largely depends upon the thoroughness and completeness with which they are mixed and amalgamated. In some cases it is found necessary to grind each component separately, and afterwards mix them in the proper proportions; but most materials, such, for instance, as limestone and clay, though totally dissimilar as regards their physical properties when in the wet state, will, after thoroughly drying, admit of being ground up together, the grinding greatly assisting in their amalgamation.

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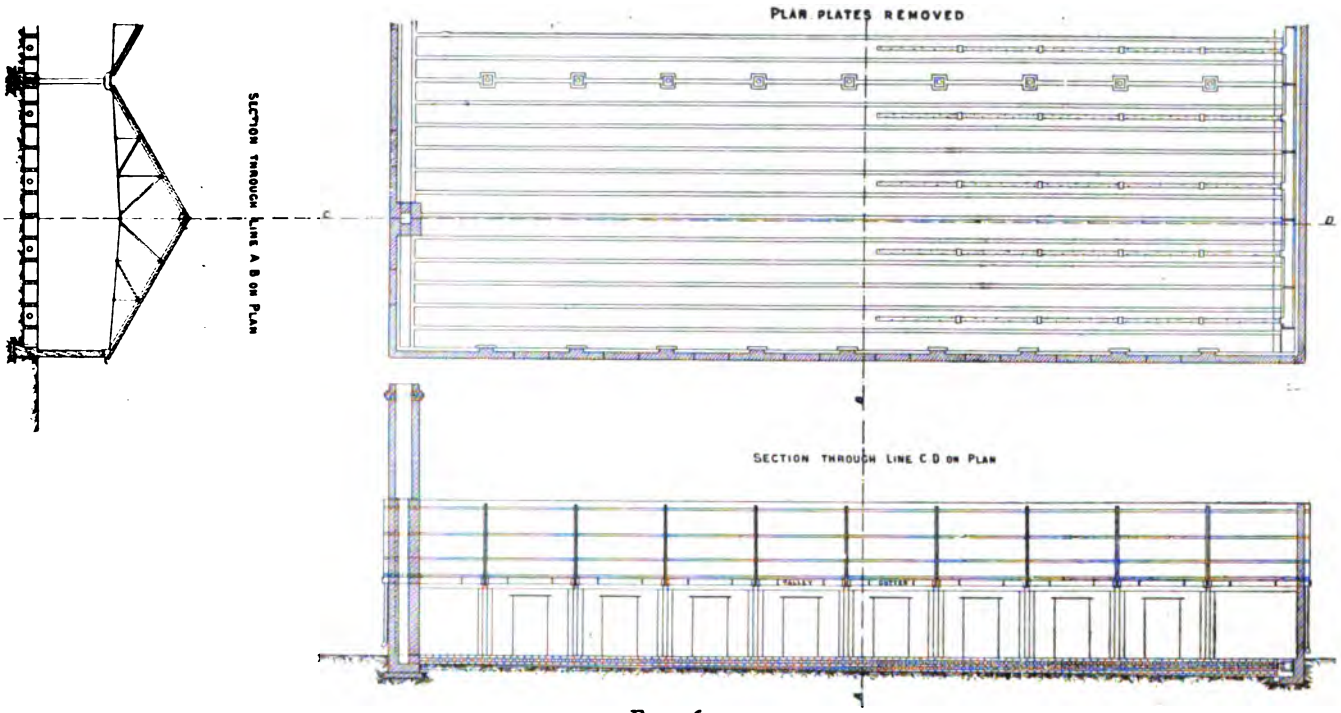

FIG. 46.

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As in the wet process, many manufacturers, in order to ensure the thorough amalgamation of the raw materials, and uniform composition of the compo, pass the powder, after it leaves the grinding mills, into large mixing hoppers of special design, having a capacity of about 40 tons, in which the material is thoroughly mixed and rendered uniform, before being passed to the damping and brick-making machinery. There should be at least two of these hoppers, according to the capacity of the works, so that the contents of one may be tested and adjusted, while the other is being filled.

The grinding machinery used for reducing the raw materials is practically the same as that already described for grinding cement clinker, the primary reduction being effected by the usual Blake or similar crusher, and the final pulverisation being accomplished by millstones or other convenient machinery. When millstones are used, it is not necessary as a rule to sift the ground material before passing it on to the pug-mills, the fineness of the powder generally being sufficiently assured; but with edge-runner mills and others of a similar nature, sieves of course are necessary, as these mills depend largely on their sieves to ensure proper reduction. When sufficiently ground, the powder passes by a shoot into the trough of a horizontal pug-mill or mixer, where it is thoroughly mixed, and beaten up with just sufficient water to enable it to be made into bricks. This mixer consists of a semicircular trough about 15 feet long and 18 inches in diameter, according to the amount of material it has to deal with, through which runs a shaft fitted throughout its whole length with a series of blades set at an angle, similar to those of a screw propeller, which mix the powder and carry it forward to the discharge outlet, where it is taken up by the brick machine and made into bricks. These bricks are then conveyed to the drying

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floors, and thoroughly dried before being loaded into the kiln for calcination.

At some works, instead of pressing the compo into bricks, it is cut off as it leaves the pug-mill into irregular lumps, which are dried and loaded into the kiln in the usual way, the contention being that these irregular lumps, being more porous than the tightly pressed bricks, are consequently more thoroughly and evenly burned. Personal experience suggests that the heat has greater difficulty in penetrating the dense compact mass of a pressed brick than the more porous irregular lump, and therefore the mass is more liable to be insufficiently calcined in the centre with the former than with the latter method.

The drying of the bricks or compo before loading into the kilns is effected in a variety of ways, according to the circumstances of the case, sometimes by means of the waste heat from the kilns, sometimes by exhaust steam, and sometimes by special furnaces. There is, of course, considerably less water to be evaporated in the damp bricks or compo than in the fluid slurry of the semi-wet process of manufacture, and therefore much less heat is required for drying a given volume of raw material. At some works the waste heat from the kilns is utilised for drying both the wet clay and also the compo bricks. In such cases the brick or compo drying floor is arranged at the level of the top of the kiln, as with the Johnson chamber, and the clay drying floor beneath, so that the hot gases are first led under or through the upper drying floor and then down through flues to the clay drying floor beneath; thus the whole of their heat is utilised before they are allowed to escape by the chimney. It is hardly necessary to add, that to enable this to be carried out efficiently, a very strong draught is required to draw the gases through at sufficient velocity.

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At one works, which the author recently had the opportunity of inspecting, the bricks were pressed fairly dry, and loaded into chambers built around the dome of an ordinary bottle kiln, so that the only heat available for drying purposes, was that radiating from the brickwork of the dome, which seemed quite sufficient for the purpose, and saved the expense of constructing the usual kiln chamber of the Johnson type.

Where the bricks are dried by waste heat from the kilns by means of flues leading under the drying floors, it is generally found that one drying floor will dry sufficient material for two or three kilns, the waste heat passing from the kiln being sufficient to dry the bricks in a couple of days. When working on this principle it is usual to construct the kilns with an open dome similar to Fig. 15, but with flues leading out from the side to the drying floor. Both dome and flues are fitted with dampers, so that the kiln is allowed to burn as an ordinary open kiln until the fire gets through the mass, when the dome damper is shut down, the flue dampers opened, and the hot gases made to pass under the drying floor to the chimney beyond. Owing to the small amount of drying required by the bricks or compo, a drying floor of one kiln capacity can be stripped three times a week, and thus made to serve three kilns.

Although a mixer or pug-mill is generally used for the final amalgamation of the powder, the makers of the tube-mill described on page 156, claim that when that mill is used for the final powdering of the raw materials, the treatment to which it is subjected therein so thoroughly amalgamates the powder that further mixing is unnecessary. From personal examination of a sample of compo produced by the tube-mill only, this seems to be the case. The same firm also supply a brick machine, which they claim will dry-press the bricks with such a small amount of water that they are

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ready for loading into the kiln immediately, without further drying. If such a process should prove to be practicable, it would be very economical, both as regards labour and fuel for drying purposes, though there is the objection previously mentioned with regard to the proper calcination of such densely pressed bricks; it seems that to press them with such a small amount of water as to be dry enough for immediate calcination, they must necessarily be so extremely dense and compact that they would not burn satisfactorily under ordinary conditions of calcination. In confirmation of this view, the author was recently told by a Colonial cement manufacturer, that he had experienced considerable trouble in trying to work on these lines, and had come to the conclusion that his materials, i.e. limestone and clay, which produced a good damp pressed brick, were not suitable for treatment as such extremely dry pressed bricks.

Where the raw materials are practically alike in hardness and physical properties, such as the limestones and shales of the Lias formations of Warwickshire, they are fed in together through the crushers in the correct proportions, and then elevated to the millstone hoppers by the ordinary belt or chain elevator. The subsequent grinding of the crushed materials further assists their intimate mixture, and the ground product, as it leaves the stones, falls into a circular mixing pan of about ten feet diameter, where sufficient water is added to form it into a moderately thin paste, just fluid enough to enable it to be spread evenly on the drying floors with a rake. The mixing pan for this wetting process is something like a wash-mill on a small scale, having horizontal radiating arms driven from a central vertical spindle, but instead of harrows suspended by chains, it simply has vertical knives or stirrers fixed to these arms. The dry powder being fed in at the outer

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circumference and water being at the same time added, the material is carried round the mill by the stirrers and gradually works towards the centre, where it overflows through a circular opening in a perfectly mixed and evenly wetted condition.

The "shammuck," as the semi-fluid material thus produced is locally termed, is then conveyed to the drying floors in trolleys or by mechanical conveyors, where the added water is driven off, preparatory to its being loaded into the kilns for burning. At one works where this process is adopted, a rather ingenious tool is used for levelling the shammuck on the floors, by which means it is caused to dry in blocks of a convenient size for loading into the kilns. This tool consists of a kind of wide rake with a high back and long teeth, the latter being of such a length and placed at such a convenient distance apart, that when the mass is carefully levelled with it, it is scored in parallel grooves, and by drawing the rake through the material again at right angles to its previous course, the shammuck is divided into lumps of about 4 or 5 inches square, which readily separate when dry, the regular size of the lumps thus produced ensuring more accurate burning.

The dried shammuck made by this process is considerably less cohesive, and not nearly so tough as the dried slurry made from chalk and clay by the wet process, and therefore greater care has to be exercised to prevent dusting while being loaded into kilns. If tipped from barrows direct into the kilns, as is the custom with ordinary chalk slurry, it would crumble to a very large extent, and thus choke the draught of the kiln. It therefore has to be lowered in shallow baskets to the loading level by means of a whip, where it is gently tipped into position. This seems rather a laborious process to those accustomed to

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work with the tougher chalk slurry, but experience has doubtless shown it to be necessary.

The burning and grinding of the mixed material in the dry process of manufacture is the same as in the wet processes, and therefore a detailed description of it would be mere recapitulation. It has been found, however, that the clinker produced by the former process is considerably denser and more difficult of reduction than that produced by the latter process, the result being that some of the edge-runner and other patent mills, which have met with a fair amount of success in the Thames and Medway districts, have not been equally successful in treating the clinker produced from the Lias formations.

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THE TESTING OF PORTLAND CEMENT.

CHAPTER I.

INTRODUCTORY.

THE object of testing cement is to ascertain its value as a constructive material, and also to determine, as far as possible, the characteristics which it may be expected to develop in practical use. This is, of course, chiefly the object of testing from the user's and scientific point of view; the manufacturer, while he is doubtless interested in the characteristics ultimately developed by his cement, is generally satisfied if it is equal in quality to the tests demanded of it by the specification of the user, and, considering the very varied requirements of the different specifications he often has to work to, this is not altogether surprising. The tests which are generally carried out to ascertain the quality of cement are the following:—

1. Soundness, i.e. freedom from destructive agencies within itself, or, as it is generally termed, "blowing."
2. Fineness of grinding.
3. Strength, cohesive and adhesive.
4. Setting properties.
5. Weight or specific gravity.
6. Chemical composition.

The above tests, carefully carried out, enable a fairly accurate opinion to be formed as to the future behaviour

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of a sample. It would be as well, however, to point out that a totally erroneous conclusion may be arrived at by placing too much reliance on any one test by itself, such, for instance, as the tensile strength at seven days only, without at the same time carefully examining the other properties of the sample. Judging from remarks that are commonly heard on the subject, and the specifications that are often seen, the opinion seems to be very prevalent among the less well informed, that if a sample, when gauged neat, develops a good tensile strain at seven days, there is nothing more to be desired; whereas it very often happens, that a sample which, viewed from that standpoint alone, is perfectly satisfactory, shows marked signs of disintegration at the end of a month or so, and proves finally to be utterly worthless. Moreover the seven days' test by itself, in common with other tests at the one date only, gives no indication as to whether the cement will increase in strength with age, as all good cement should, or whether it practically attains its greatest strength at that date. It is therefore important to ascertain the strength developed at two dates at least, by which means an opinion can be formed of its power of growing or increasing; for it is very evident that a sample which attains a moderate strength at the earlier date and practically goes on increasing indefinitely, is more valuable for most kinds of constructive work than one which attains a comparatively high strength at the earlier date, and then ceases to increase and possibly shows a falling off.

A great many users look askance at a high tensile strain at short dates as indicating an overlimed cement, or at all events, one that is so fully limed as to contain an element of danger; although this opinion is to a certain degree well founded, it by no means always follows that such is the case. On the other hand, it is by no means

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safe to assume, as some users do, that a moderate tensile strain at seven days is an indication of soundness or a moderate amount of lime, for cases frequently occur in which a moderate or low tensile strain is unmistakably due to incipient disintegration. In such cases, of course, it is only by taking the soundness of the sample in conjunction with the other tests, that a true opinion can be formed of its quality, and the matter is only mentioned with the view of demonstrating how entirely erroneous may be the conclusions derived from a single isolated test.

The manner in which the sample is taken for testing purposes is a point which does not always receive the consideration it deserves. To obtain a good average sample of any special shipment or delivery, it is scarcely sufficient to take the whole or part of only one sack or barrel as representing the whole of the bulk, as that particular sack or barrel may contain portions of slightly damaged cement, and therefore scarcely be up to the average; or, on the other hand, it may be rather better than the remainder. It is much more satisfactory to take a sample from at least ten or twelve sacks, say from every 100 tons, and thoroughly mix the samples thus obtained; it is also advisable to take the sample from well down into the heart of the sack or barrel, and not from the mouth or surface, where it may have become slightly air-set or damaged by damp.

It is perhaps hardly necessary to add that the bag or box in which the sample is placed should be perfectly clean and free from any extraneous matter. Inattention to this obvious detail once caused a considerable amount of unnecessary trouble, and very nearly led to the cement under examination being condemned. When the sample in question was made up into pats and briquettes for testing in the ordinary way, it was found that circular stains

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or blotches about ¼ inch in diameter, of a reddish-brown colour, gradually formed on the surface of the cement, an hour or two after gauging; in the section of the week-old briquettes, soft areas were also found, apparently emanating from the same cause, and owing to these soft places, the tensile strain developed was very inferior, while pats examined for soundness showed decided signs of expansion. In sifting the sample in the ordinary way, to ascertain its fineness, one or two crystals were noticed among the coarse particles, which, on being cleansed from the dust adhering to them, proved to be nothing more nor less than grains of ordinary crystallised sugar, and on examination of the bag in which the sample arrived, similar crystals were found adhering to the interior of it. Evidently the sample had been put into an old sugar sack that had not been properly cleaned, and some of the particles of sugar becoming detached during the railway journey, mingled with the cement, and thus caused the peculiarities before mentioned. It is well known that a solution of sugar has a very deleterious effect upon cement, and that it was responsible for the mischief in this instance was proved by adding two or three of the grains found in the faulty sample to another cement, with exactly similar effects; as a further proof, a fresh sample of the original cement, forwarded in a clean sack, gave perfectly satisfactory results.

The exact manner in which the tests mentioned at the commencement of the chapter are applied, is a matter which often gives rise to considerable discrepancies, each engineer having his own ideas on the subject, and naturally insisting on their being adopted. In the following pages it is proposed to discuss the methods most generally used for testing cement, together with some description of the machines and apparatus employed for that purpose.

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CHAPTER II.

SOUNDNESS.

THE soundness of a cement is the most important feature to be determined in testing a sample, and it should always be first examined in that direction; it is very evident that, no matter what other excellent qualities a cement may possess, such as being very finely ground, or developing a high degree of strength at comparatively short dates, if it eventually expands and disintegrates, it is at once converted into a destructive agent, instead of being a constructive material.

The original method of testing cement in this particular, was to make a thin pat with tapering edges and place it in water as soon as set. If at the end of a week, or other given period, it developed no cracks or alteration from its original form, it was considered sound. From personal experience this method is not by any means reliable, as more than one instance has occurred in which pats thus treated have been perfectly satisfactory when examined at the expiration of seven days, and yet at the expiration of a longer period, both pats and briquettes have been found to exhibit signs of expansion. Care must be taken, however, to make sure that the pat is set hard before being plunged in water, as almost all slow setting cements, if immersed when half set, will, within a few hours, crack or fly on the surface during completion of setting, and frequently lift from the glass plate. Sometimes, as a further test, similar pats are left in air and others plunged into water immediately

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after gauging. Although if the cement is in the least unsound, these "plunged" pats will be the first to develop cracks, it does not by any means follow that if cracks do occur, that the cement is therefore unsound; instances have recently come under the author's notice in which plunged pats developed surface cracks within a few hours of gauging, and yet the cement satisfactorily withstood the most drastic hot water tests, even boiling. In this case it seems to be a surface cracking only, due to some peculiar effect of the water on the skin of the cement during the setting, since the cracks do not penetrate more than an $\frac{1}{8}$ inch or so below the surface. Some 2-inch cubes composed of neat cement and also 3 to 1 sand cement mortar, plunged immediately, did not even develop surface cracks, indicating that these defects would not occur in practice with a large bulk of concrete under water.

The most reliable method for testing cement for soundness, in the author's opinion, is that brought out some twenty years ago by the late Henry Faija, and now commonly known as the "Faija" test for soundness. It consists in subjecting a freshly gauged pat to a moist heat of 105° to 110° F. for six or seven hours, or until thoroughly set, and then immersing it in warm water at a temperature of 115° to 120° F. for the remainder of the twenty-four hours. By this means an artificial age is imparted to the cement, and any vicious qualities which it may possess are quickly brought to notice. A sketch of the apparatus used for this purpose is shown in Fig. 47. It consists of a covered vessel in which water is maintained at an even temperature of from 115° to 120° F. It will be seen that the space between the two vessels is filled with water, which acts as a kind of protective jacket and assists in equalising the temperature of the inner vessel; the latter being filled with water only to the height shown, the space above the water is conse-

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quently full of the vapour arising therefrom, and is at the required temperature of 105° to 110° F. Immediately a pat is gauged, it is placed over the water on the rack provided for that purpose in the upper part of the vessel, where it is left for five or six hours until thoroughly set, at the end of which period it is placed bodily in the warm water. A pat made in the morning and placed in the

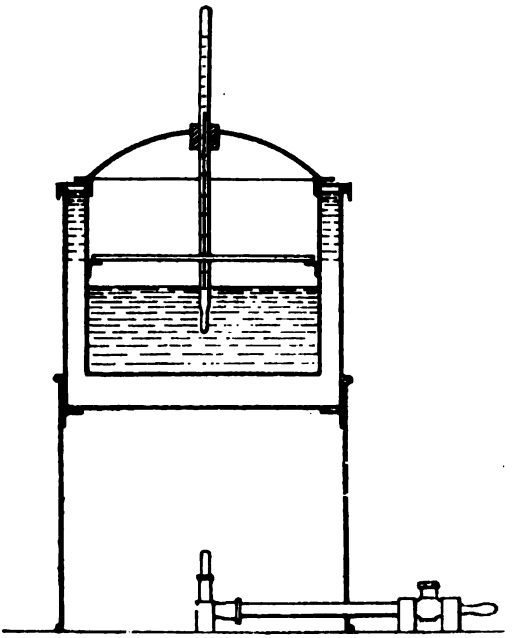

FIG. 47.

warm vapour at once, may be plunged in the water towards the end of the afternoon, and the next morning an opinion can be formed of the soundness of the sample. The author has had a long experience of this apparatus, having first used it in the laboratory of the inventor for seven or eight years, subsequently at cement works, and later in his present practice, and he has always found it

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perfectly reliable. If a pat treated therein at the prescribed temperatures shows no signs of cracking or blowing at the end of the twenty-four hours, and adheres firmly to the glass plate on which it was made, the cement may be used with perfect confidence; it will never "blow." If, on the other hand, the pat shows slight cracks, or blisters badly on the under surface next the glass, it is a danger signal, so to speak, which should not be disregarded. But before condemning the cement off-hand, it is as well to ascertain if these signs of unsoundness are due to the really bad quality of the sample, or merely to its being too fresh or hot, consequent on having been recently ground. For this purpose it is necessary to spread the sample out in a thin layer for a day or two in a cool dry place, and then try it again. If on the second trial the obnoxious characteristics hitherto developed have disappeared, it may be safely assumed that the cement was merely too fresh, and will be safe to use after judicious aëration and maturing.

Particular care must be taken that the specified degrees of temperature are closely adhered to, as if the temperature of the water falls much below 115° F., a faulty cement very often goes undetected, whereas if it is allowed to rise much above 120° F., a cement may be condemned that will give perfectly satisfactory results in practice. To guard against the latter contingency, a maximum thermometer is placed in the bath before leaving for the night, so that any excessive temperature may be recorded. Where gas is used as a heating agent, especially in large towns, it will generally be found that the pressure increases, and consequently the temperature rises, about ten o'clock at night, i.e. when shops are being closed and the consumption is reduced.

The following may be cited as an instance of the importance of the proper temperature being maintained. A cement sent to the author's testing room for examination

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and report in the ordinary way, had, according to the terms of the specification, to withstand a temperature of 90° to 100° F. without showing cracks or signs of deterioration; submitted to that temperature, the pats were perfectly satisfactory, but when subjected to the temperature of the "Faija" test, viz. 115° to 120°, the cement showed decided signs of expansion. This cement developed a good tensile strain at seven days, and the ordinary cold water pats were perfectly satisfactory, yet at the expiration of twenty-eight days, the briquettes had decreased in strength, and showed distinct cracks and signs of incipient expansion, while at the end of three months they had disintegrated altogether. Suspecting at the time some such result from the indications of the "Faija" test, the precaution was taken of spreading out some of the cement to aërate for a day or two, until the unsatisfactory indications previously noticed were no longer developed, and then having a further set of briquettes made from it for the twenty-eight days' test. These briquettes were perfectly sound at that date, and the tensile strain showed a good increase over that developed at the seven days. This example demonstrates the importance of adhering carefully to the requisite temperatures, and also shows the value of cooling or maturing cement before use.

Another advantage, by no means inconsiderable, of the "Faija" test, is that it takes only twenty-four hours to determine whether a given sample is sound and fit for use; whereas the ordinary cold pat method takes at least a week, and even then is not always conclusive. In fact, speaking broadly, if a cement is well ground and will satisfy the requirements of the "Faija" warm water test, it is almost invariably good enough for any constructive purposes. An American correspondent, writing to the author a short time ago, assured him that, as a rough method of

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testing cement, where expensive testing machines and plant were not available, he invariably used the "Faija" test in conjunction with the fineness, and always found the results satisfactory.

The unsoundness of cement is generally due to one of two principal causes, viz. either to overliming or to underburning, both giving rise to "free" or loosely combined lime, which expands on contact with water and causes disintegration. In the first instance, the cement contains more lime than can chemically combine with the other ingredients, even after proper calcination; in the second case, although it contains the normal proportion of lime, it has not been subjected to a sufficiently high temperature to enable that lime to combine thoroughly with the other constituents. Of these two forms of unsoundness, by far the more insidious and deadly is that due to overliming; a cement that is overlimed is very often thoroughly burned, and therefore, being difficult of reduction by the grinding machinery, the coarser particles contain the germs of destruction, which may not develop for weeks or even months after the cement has been placed in work. With an underburned cement, on the other hand, the clinker is soft and easily reduced to a fine powder, and by this means the uncombined lime is more freely exposed to the moisture in the atmosphere, and thus more readily slakes and purges itself of its dangerous property. Moreover, a cement that contains free lime from underburning, "blows" in a distinctly different manner to one which is well burned but overlimed. The underburned cement, if mixed with water before it has become sufficiently aërated to slake off the "free" lime by exposure to the air, simply expands in the same rapid manner that a cement containing a small admixture of quicklime would do, owing to the rapid hydration of the uncombined lime in its composition. The damage

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is generally but slight, and has often run its course in a day or two. With a cement that is overlimed and well burned, on the other hand, although the finer particles may have been sufficiently matured for the "free" lime to have become hydrated, and therefore harmless, the coarser particles, or grit, which contain the destructive properties, are less readily attacked by the water, and these particles subsequently expanding and disintegrating, cause the mass itself to expand and sometimes crumble to pieces.

An example of each of the above kinds of "blow" once occurred at a cement works where additional kilns were being erected. In putting in the concrete of a retaining wall, the workmen inadvertently got hold of some of the underburned dust which had been thrown out from an adjacent kiln, which they mixed in with the rest of the concrete. The next morning the face of the work showed decided cracks and signs of expansion. These cracks, however, developed no further after the first two days, showing that the hydration of the free lime was completed within that period. In the other instance, where the cement used was evidently overlimed, the cracks did not show for about three weeks, and then gradually got worse and worse, till in about four months' time the work had disintegrated entirely.

A test for soundness of a similar nature to the "Faija" test, is that advocated by the late Sir John Coode. It consists in warming pats of cement in an ordinary oven to a temperature of about 170° F., and at intervals, while still warm, brushing them over with cold water. The pats, however, have to be seven days old before they can be subjected to this test, and this condition, compared with the "Faija" test, is the main objection, inasmuch as a week has to elapse before an opinion can be formed of the soundness of the sample. The author has not had a very extensive ex-

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perience of this test, having only tried it in comparison with the "Faija" test for about a twelvemonth, some fifteen years ago. As it was found that both tests gave practically identical results, the Coode test was abandoned in favour of the "Faija" test, the latter being so much more speedy in its operation. Of course, the one advantage of the Coode test is that it requires no special apparatus, the pats being merely heated in an ordinary oven at the required temperature.

The hot water test of M. Deval consists of treating pats of cement that have been left in the air as usual for twenty-four hours, in a hot water bath at a temperature of 80° C. (176° F.) for six days or longer, after which treatment they are to show no cracks or signs of expansion. This test has also been elaborated as a means of determining, within a few days, the tensile strength which a cement will develop in cold water under ordinary conditions at longer periods. After one day in air and three days in the hot bath, the tensile strain developed is required to be equal to that attained in seven days when immersed in ordinary cold water in the usual manner of testing, and, similarly, after one day in air and six days in the hot bath, the sample is required to develop the same strength that it would in the ordinary way after one day in air and twenty-seven days in cold water. The author's experience is that few cements will bear this high temperature without showing cracks and signs of deterioration; and as many cements which failed to pass this test have, to his knowledge, given perfectly satisfactory results in practical work, he is of opinion that it is needlessly severe. It should, in fact, be made use of in a negative sense only, i.e. if a cement does not show any cracks or signs of expansion when subjected thereto, it may be safely concluded that it will not develop any signs of disintegration under the ordinary conditions of practical

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use; but on the other hand it is a little hard on the manufacturer to condemn his cement, merely because it will not bear immersion in water of a temperature of 176° F. within twenty-four hours of gauging. When assisting Faija in his experiments some twenty-three years ago as to the most suitable temperature to use with his apparatus, it was found that the range previously mentioned, viz. 115° F. to 120° F., gave the most reliable results. It may be mentioned that this apparatus was really founded upon a patent (No. 875, of 1881) for accelerating the hardening of purpose-made concrete goods, with the view of reducing the number of moulds and the necessary stock required by the manufacturer of such goods. It was found that by the judicious application first of a moist heat and subsequently of a warm bath, the concrete attained the strength of several weeks in a few days; one or two cements were found to give unsatisfactory results in this process, and by observation it was found that those cements which failed under the warm bath treatment, afterwards showed cracks and signs of deterioration when treated in the ordinary way in cold water, though sometimes it was weeks or even months before such indications developed sufficiently to become noticeable. These observations led the inventor to make further experiments on the subject, and the outcome of a series of careful experiments resulted in the apparatus now known as the "Faija" apparatus for soundness. In 1891, when the merits of the Deval test were somewhat loudly boomed by the technical press, Faija carried out an extensive series of experiments as to the comparative merits of his own process and that of M. Deval, as regards the tensile strength of cement, artificially developed by means of a warm bath. The results showed that there was very little difference between the two, viz. that a temperature of 115° to 120° F. imparted an artificial age to the briquette equally well as a temperature

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of 176° F., while the former process tended less to condemn a really good and serviceable cement.

Several modifications of the Deval test have been brought forward during the last few years, most of which are based on a temperature of 212° F., or boiling point, instead of 176° F. The most popular from the user's point of view, probably because it is the easiest of application, is to make a pat about 4 inches diameter and ½ inch thick, tapering to nothing at the edge, and allow it to set in air for twenty-four hours covered with a damp cloth; it is then placed in a vessel of cold water which is gradually heated, until in about half-an-hour, it is raised to the boiling point, and maintained at that temperature for about five hours, after which treatment the pat is to show no signs of cracking or deformation, and to break with a crisp ring. This is a very drastic test, and the user may be quite satisfied with the soundness of any cement which passes it satisfactorily, but the author would be very chary of condemning a cement simply because it failed to pass.

A very neat and well thought out method of measuring the actual expansion or contraction of cement, is that devised by Prof. Bauschinger for testing bars 100 mm. long and illustrated in Fig. 48. A stout brass framework A, shaped to allow easy manipulation of the bar of cement, is arranged with two moveable points, which fit into metal eyes set in the ends of the bar. One of these points (at the right hand end, as seen in the diagram) is the point of a vernier micrometer B, of which B is the wheel, graduated round its circumference into 100 parts, each of which corresponds to $\frac{1}{200}$ mm.; and C is the fixed scale divided into half millimetres. The other point D, is a long bent lever D, pivoted near the point, and bent upwards in a slender arm moving over a scale F, and kept in close contact with the bar by the spring E. The object of this lever arrange-

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ment is to ensure a perfectly accurate contact with both of the clipping points, without danger to the bar, if soft, or the micrometer screw, should the bar chance to be too hard to suffer damage in this way. A handle is fixed

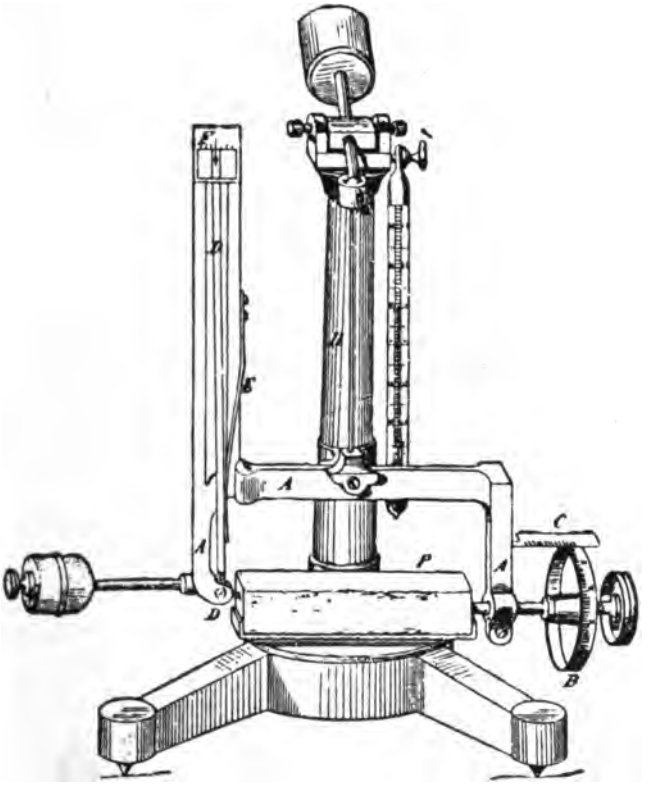

FIG. 48.

rigidly on the framework at the left hand, and a small handle on the micrometer wheel to prevent the graduations wearing off.

The framework A is lightly hung from a swing arm, which allows free vertical movement of the framework

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carrying the bar, and is balanced by a heavy brass weight at the back end. The arm is arranged to move through the pivoted block at the top of the supporting column H, mounted on a tripod-shaped base; and is adjusted so that when the test bar is in the clips, the whole is evenly balanced. A thermometer is hung close to the measuring apparatus, to add corrections whenever extreme accuracy is desired, or a large range of temperature met with. The measurement is effected by placing the bar or prism of cement on the platform provided, and after carefully cleaning the eyes of any cement or other matter which may have accidentally got in, the point D is placed in the eye at that end, and the screw point is very carefully screwed into the opposite eye; the screw is stopped when the pointer D is exactly opposite the middle point of the scale F. It is very often found necessary, however, to gently wriggle both clips successively in the eyes, to avoid the points sticking in the wrong place; the same object may also be effected by lifting the beam, while in the clips, off the platform, and gently spinning it on the points. The screw is then twisted again to readjust the needle D on the centre of the scale F, and the reading taken. The reading on the scale is easily converted into the actual measurements of the test prism. The reading on C is expressed as a whole number, say 7, and on the wheel as hundredths, say 48; then the beam actually measures 7·48 half millimetres, i.e. 3·74 mm., in addition to the standard length from the point of D to the point of B, when the scales are at zero, viz. 95 mm. Thus the bar measures 95 + 3·74 mm. = 98·74 mm.

Carefully measured bars of cement and wood are supplied, with their lengths, and corrections for change of length due to variation in temperature, inscribed thereon, which are used to test the accuracy of the graduations, and

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allow for wear of the points by use. The bars never vary much in length from 100 mm., and therefore the increase or decrease in the length of a bar is expressed directly in. percentages.

This apparatus is also adapted for measuring the

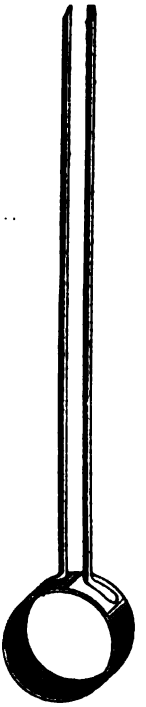

FIG. 49.

expansion of cement after subjection to a hot water bath of any desired temperature, and may thus, as with the hereafter described Chatelier test, be termed a quantitative test for expansion, in contradistinction to the ordinary pat tests, which are only qualitative.

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Another device, for measuring expansion, is that designed by the well known French scientist, M. H. Le Chatelier, an illustration of which is given in Fig. 49. It consists of an expansion ring or vertically split cylinder of thin metal, 30 mm. diameter and 30 mm. deep, which acts as the mould for the cement, and the ends of which butt closely together when empty. Close to each side of the split, are soldered two horizontal brass needles, parallel with each other, 150 mm. in length. If there is any expansion in the cement, the metal ring is forced open, and the ends of the needles serve as indicators, to show, in an exaggerated form, the opening of the ring.

The test is performed by filling the ring with neat cement, gauged in the ordinary manner, first securing the ring with a rubber band; it is then covered with a slip of glass and immersed in cold water for twenty-four hours; the rubber band is then removed, and the distance between the points of the wire arms measured. The cement and the ring are then placed in a vessel of water, which is gradually heated, until in about an hour boiling point is reached, and maintained at that temperature for three hours. After that period they are removed from the water, and allowed to cool. The measurement between the points is again taken, and the increased distance of the points is taken as the expansion. In case the arms get bent, so as to cross, when filled with gauged cement, it must be borne in mind that the distances between the points, before and after, must be added together, instead of subtracted. 12 mm. has been fixed as the maximum expansion allowable by a sound cement.

A test for expansion which appears to be gaining popularity is to fill a test tube of about 1 inch diameter with freshly gauged cement, and note if at the end of a week it expands and cracks the tube. This test certainly has the

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merit of simplicity, but since, according to Ganot's Physics, the coefficient of linear expansion between 1° and 100° C. of glass is 0·00000813, and wrought iron (which is the same as cement) is 0·000012204, it is reasonable to assume that the cracking of the tube may be quite as frequently due to variations in atmospheric temperature, as to any inherent fault in the cement.

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CHAPTER III.

FINENESS.

NEXT in importance to the soundness of a sample the author would rank the fineness to which it is ground, as it is very evident that the finer a sample is ground, the greater will be its covering power, and therefore the greater its value as a cementing material, to say nothing of the other inherent advantages of fine grinding.

The fineness of a cement is ascertained by sifting a given weight through a sieve or sieves composed of brass wire gauze, having a given number of meshes per square inch. For practical purposes, it will be found sufficient to take 100 grammes, and after sifting until no appreciable further quantity can be got through, the residue is weighed, the weight in grammes of course representing the percentage of residue retained by the sieve used. When the fineness on two or more sieves is to be ascertained, it is usual to sift through the finest one first, and treat the residue retained on each sieve through the next in point of coarseness, till the coarsest one is reached. This method is accurate enough for all practical purposes, but where extreme accuracy is required, it becomes necessary to take a fresh quantity of cement for each sieve, as by the attrition of the particles one upon the other in prolonged sifting, their diameter is slightly reduced, and, as shown hereafter, an unduly favourable result is obtained.

The percentage of residue by measure is a method very

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often adopted in cement works by t
charge of the grinding machinery, to a
passing to the warehouse is of the d
ness. For this purpose two measure
composed of brass or other convenier
to breakage, the larger one having a
a pint, and the smaller one holding
quantity of the larger; the smaller m
tenths, by means of a vertical strip of
ten equal divisions, fixed to the insid
the top to the bottom. The larger m
with cement, and the contents sifted
sieve; the residue is then measured in
sub-division representing 1 per cent
of course, is only an approximate m
the fineness, as the result depends la
ness with which the measure is filled
and also in a lesser degree on the ar
residue in the smaller measure recei
is read off. It is, however, sufficien
as a guide to the miller, and it obvia
which in the dusty atmosphere of
not long retain their accuracy.

Fine grinding is a matter in whic
facturers were for a long while ahead
petitors; but the latter have recently
fact that, if they wish to maintain
Transatlantic and other markets, th
grinding of their manufacture, and cc
taken vigorous steps in that directic
ago, 10 per cent. on a 50 sieve,
a 76 sieve, was considered a well
now a number of our principal ma
grind down to less than 5 per

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No. of Sample.	1880			1890			1895			1900			1905		
	Residue per cent. after Sifting through Sieves Nos.			Residue per cent. after Sifting through Sieves Nos.			Residue per cent. after Sifting through Sieves Nos.			Residue per cent. after Sifting through Sieves Nos.			Residue per cent. after Sifting through Sieves Nos.		
	25	50	70	25	50	70	25	50	70	50	76	100	76	100	180
1	8·0	32·0	..	..	1·0	7·0	..	4·5	11·5	nil	0·2	4·8	1·0	6·0	23·0
2	6·0	29·0	..	0·3	6·0	16·0	trace	0·5	6·0	0·2	3·6	12·0	0·2	0·6	11·0
3	8·0	33·0	..	0·3	7·5	18·0	..	trace	2·5	0·2	2·0	8·0	2·0	6·0	22·0
4	4·0	27·0	..	0·1	6·0	15·0	..	1·5	5·5	0·4	4·6	13·6	3·0	9·0	26·0
5	nil	14·0	30·0	0·1	3·5	11·0	..	1·0	4·5	trace	3·0	13·0	1·0	5·0	22·0
6	0·5	21·0	32·0	..	4·0	17·5	..	1·3	6·0	trace	0·8	7·6	0·6	2·0	14·0
7	2·0	21·0	31·0	0·5	4·0	11·5	nil	0·6	5·0	trace	1·0	6·6	0·6	1·6	18·0
8	1·0	21·0	34·0	0·1	6·0	14·0	..	3·0	7·5	0·4	3·8	11·2	1·0	4·6	18·0
9	4·0	20·0	29·0	..	1·0	9·0	..	1·0	4·5	0·4	2·0	9·6	0·6	2·0	13·6
10	3·0	24·0	35·0	0·75	8·0	15·0	..	2·5	7·8	trace	2·0	10·8	2·0	6·0	20·0

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and only a trace of residue on a 50 sieve, while for some contracts they are compelled by the terms of the specification to grind to less than 10 per cent. on a 100 sieve, or one having 10,000 meshes per square inch. The preceding results, taken indiscriminately from our testing books of 1880, 1890, 1895, 1900, and 1905, may be interesting on this point, as showing the improvement that has taken place in regard to fineness during the last twenty-five years.

A point which is often overlooked in testing cement for fineness, is the thickness of the wire of which the gauze is composed, as it is very evident that the thicker the wire used, the smaller will be the aperture through which the cement has to pass, and *vice versâ*. Unfortunately in England we have no agreement upon this matter; each engineer, when he specifies it at all, specifies the thickness of wire which meets his fancy, and the result from a manufacturer's point of view is often very annoying. This matter was dealt with by the author in a recent paper * on the subject, from which the following extract is quoted:—

"The thickness of wire of the various testing-sieves" "adopted by the late Henry Faija and afterwards con-" "tinued by the author was as follows:"

No. of Sieve.	New Standard Wire Gauge.	Thickness of Wire.	Width of Opening.
sieve		inch	inch
50 × 50	35	·0084	·0116
70 × 70	38	·006	·0083
76 × 76	39	·0052	·0079
80 × 80	39	·0052	·0073
100 × 100	41	·0044	·0056
120 × 120	43	·0036	·0047
180 × 180	45	·0028	·0028
200 × 200	46	·0024	·0026

* 'Proceedings, Society of Engineers,' 1903, p. 90.

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"On the Continent and in America the standard"
"adopted, for the sake of uniformity, is that the thickness"
"of the wire shall be one-half the size of the opening"
"—i.e. in a sieve having 100 holes per lineal inch the"
"size of the opening would be $\frac{2}{3}$ of $\frac{1}{100}$ = ·0066 inch, and"
"the thickness of the wire of the gauze $\frac{1}{3}$ of $\frac{1}{100}$ = ·0033"
"inch. Being the only standard of the kind in existence,"
"and in order to bring his results into line with Continental"
"and American practice, the author has recently adopted"
"this standard in his testing rooms. The following table"
"gives the thickness of wire of the various sieves, and the"
"corresponding size of the aperture :

No. of Sieve.	New Standard Wire Gauge.	Thickness of Wire.	Width of Opening.
sieve		inch	inch
50 × 50	37	·0068	·0132
70 × 70	40	·0048	·0095
76 × 76	41	·0044	·0087
80 × 80	41½	·0042	·0083
100 × 100	44	·0032	·0067
120 × 120	45	·0028	·0055
180 × 180	47½	·0018	·0037
200 × 200	48	·0016	·0034

Another matter which will make considerable difference in the results obtained in sifting cement through a given sieve, is the duration of the shaking or sifting process. About five minutes' vigorous shaking and tapping is generally sufficient to get through all the finer particles that really pass the sieve; if continued for half an hour, weighable portions will still pass the sieve, but the particles which pass the sieve after such prolonged shaking

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and sifting, do not really represent the actual fineness of the cement and the work done by the comminuting machinery, but are rather due to the attrition of the particles one upon another during the operation of sifting, by which they are reduced sufficiently for some small portion to pass through the sieve. As an experiment in this direction, ten ounces of cement were sifted in an 80 sieve for an hour, weighing the residue at intervals of ten minutes, the results of which were as follows :—

				per cent.
After	10	minutes'	sifting the residue was	13·5
„	20	„	„	13·0
„	30	„	„	12·5
„	40	„	„	12·1
„	50	„	„	11·9
„	60	„	„	11·7

In checking the number of holes per lineal inch which a given sieve contains, it must not be forgotten that the stretching of the gauze, in the making of a sieve, will very often cause an appreciable difference in the number of holes contained in it. For making sieves of a fine mesh, it will be found a very convenient plan to have a square wooden frame about 3 inches deep, composed of half-inch material, and simply fix the gauze to the bottom of it by screwing a slip of wood along the bottom edge. In this way there is no fear of the gauze being stretched, as is often the case, in forcing the larger hoop over the smaller one when putting together a round sieve in the usual manner.

It must not be forgotten that in addition to the increased covering power imparted to the cement by fine grinding, the danger of blowing or of disintegration is also obviated to a very great extent ; for the finer the powder, the more readily moisture in the atmosphere, or the water used for gauging, can attack and render innocuous any free or loosely

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combined lime, which would otherwise be confined within the coarse particles, and therefore the less the chance of future disintegration, caused by the water eventually penetrating and causing this loosely combined lime to expand. Special reference to this point will be found in a paper by the author on the finer grinding of Portland cement,* from which the following results and extracts are quoted :—

Cement.	——	Fineness-Residue on Sieves of Holes per Lineal Inch.			Pat Treated in the Faija Apparatus for Soundness.
		180	76	50	
L	As received from manufacturer	24·4	7·6	1·5	Blown.
„	Reground to pass 180 sieve	trace	nil	nil	Sound.
P	As received . .	18·0	3·0	0·8	Badly blown.
„	Reground as above	0·4	nil	nil	Very slightly blown.
Q	As received . .	34·8	16·0	3·6	Badly blown.
„	Reground as above	1·6	nil	nil	Sound.

The sample which first suggested the beneficial effect of fine grinding with regard to soundness was cement L. It will be seen that, as received from the manufacturer in its comparatively coarse condition, it showed signs of blowing in the Faija apparatus for soundness, but after being ground extremely fine, these indications were no longer developed, showing that the finer grinding had rendered it perfectly sound. Efforts were thereupon made to procure and similarly treat further samples of unsound

* 'Minutes of Proceedings, Institution of Civil Engineers,' vol. cxxxii., p. 350.

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cement, in order to corroborate
what surprising result. A firm
undertook to prepare a sample
worthless cement, which is desi
Figs. 50 and 51 are full-size p
made from this cement under e:
before and after extreme fine
mission of the Institution of Civ

FIG. 50.

reproduced. The results speak
is worthy of note that the few
the pat made from the finely gr
duced in the warm moist air of
veloped no further after being pla
This suggests that the slight expa
to the immediate hydration of the
by extreme fine grinding was exp

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water used for gauging, while the disastrous results in Fig. 50 were due to the gradual hydration and consequent expansion of the free lime in the interior of the coarse particles.

Figs. 52 and 53 show pats of cement, Q, under exactly similar conditions. This sample, received for testing in the ordinary course of practice, was made from an extremely hard chalk. Owing to this chalk being insuffi-

FIG. 52.

FIG. 53.

ciently reduced in the preliminary process of amalgamation of the raw materials, a decidedly unsound cement resulted, that is, when ground to the ordinary degree of fineness ; it will be seen, however, that extreme fine grinding rendered it perfectly sound. It may be interesting to add, in corroboration of the results of the Faija test, that the briquettes prepared from the original cement were badly blown at twenty-eight days, while at three, six, and

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twelve months, they were too much swollen and disintegrated to go into the clips of the testing machine, and almost fell to pieces on handling. It is needless to remark that such a cement would be worse than useless as a constructive material, for its subsequent disintegration would bring about the downfall of any building in which it might be used.

Another effect of fine grinding, though it is not perhaps such a satisfactorv one, is that it renders the cement considerably quicker setting; this, on a second's consideration, is very easily explained, and only to be expected. The setting of cement, according to Le Chatelier, is due to the water dissolving out the more soluble parts of the powder, and forming a super-saturated solution, which subsequently deposits crystals and gradually forms a solid mass. Obviously, therefore, the finer a cement is ground, the more readily the water can act on the soluble portions, and the quicker setting it becomes. Further remarks on this point, together with some experiments thereon, will be found in Chapter V., pp. 254, &c.

In all text-books on the subject, it is stated that the impalpable powder only is the active part of a cement, the coarser particles being practically an adulteration, and of no more value than so much sand. The author had never ascertained this fact for himself, and was content to accept it as such, until one day its accuracy was challenged by a gentleman who was interested in cement matters. This led the author to make an experiment on the subject, and he found that, although the coarse residue had no setting power in the proper sense of the term, it undoubtedly had a certain amount of cohesive power when placed in a mould and left under water for some considerable time, even after the particles had been previously thoroughly washed to remove any trace of flour or powder which might have ad-

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hered to them. Briquettes, composed of coarse particles, only, developed a tensile strain at twelve months, ranging from 160 to 330 lbs. per square inch, according to the size of grit employed. These results induced him to institute a further series of experiments, which, with the above, were embodied in the paper just previously mentioned,* from which the table (page 203) and extracts are taken.

The four cements experimented with were specially chosen as representing English manufacture, emanating respectively from the principal factories at Rugby, Northfleet, Grays, and the Medway. It will be seen that in each case the value of the particle is, roughly, inversely proportional to its diameter, i.e. the larger the particle the less its comparative value. If the section of a briquette thus composed is examined under the microscope, the particles appear to be surrounded by and cemented together with a white crystalline deposit. Figs. 54 and 55 are microphotographs, magnified about twenty and forty diameters respectively, of a section of a briquette, composed of particles which passed through a 76 by 76 sieve and were retained on a 100 by 100 sieve. Owing to the uneven surface of the section, the focussing of the higher-power photograph is not altogether satisfactory, but Fig. 54 gives a very good idea of the manner in which the particles are surrounded by and cemented together with the white deposit. This deposit was separated in one or two cases and subjected to chemical analysis, which showed it to consist largely of aluminate of lime. From the preceding results it seems logical to infer that the outer surface only of the coarser particle is dissolved off by the water and rendered an active ingredient; and as the smaller the diameter of the particle, the larger the area of outer surface thus exposed to the solvent action of the water within a given space, the greater is the relative

* 'Minutes of Proceedings, Inst. Civil Engineers,' vol. cxxxii. p. 347.

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TABLE SHOWING RELATIVE VALUE OF COARSE PARTICLES OF CEMENT. PARTICLES THOROUGHLY WASHED BEFORE BEING PLACED IN MOULDS UNDER WATER.

Cement.	Size of Coarse Particles.	How Treated.	Tensile Strength in lbs. per square inch.			
			28 days.	3 months.	6 months.	12 months.
F	Retained on 50 sieve . . .	Placed immediately in water	..	..	95	130
,,	Passed 50 and retained on 76 .	,, ,,	..	..	120	170
,,	Passed 76 and retained on 120 .	,, ,,	..	..	245	300
,,	Passed 120 and retained on 180 .	,, ,,	..	..	310	360
,,	Entire residue retained on 180 .	,, ,,	..	150	230	290
G	Retained on 50 sieve . . .	Placed immediately in water	..	..	47	70
,,	Passed 50 and retained on 76 .	,, ,,	..	..	105	165
,,	Passed 76 and retained on 120 .	,, ,,	..	..	175	300
,,	Passed 120 and retained on 180 .	,, ,,	..	..	185	410
,,	Entire residue retained on 180 .	,, ,,	48	133	158	262
H	Retained on 50 sieve . . .	Placed immediately in water	..	..	92	145
,,	Passed 50 and retained on 76 .	,, ,,	..	..	132	235
,,	Passed 76 and retained on 120 .	,, ,,	..	..	200	385
,,	Passed 120 and retained on 180 .	,, ,,	..	..	280	360
,,	Entire residue retained on 180 .	,, ,,	72	142	212	272
I	Retained on 50 sieve . . .	Placed immediately in water	..	..	47	85
,,	Passed 50 and retained on 76 .	,, ,,	..	..	80	145
,,	Passed 76 and retained on 120 .	,, ,,	..	..	122	225
,,	Passed 120 and retained on 180 .	,, ,,	..	..	280	430
,,	Entire residue retained on 180 .	,, ,,	53	110	170	260

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value of that particle. There is no doubt that if reduced below a certain diameter, the whole of the particle would be acted upon by the water, and would contain no internal inert matter, but at what fineness this result would be produced has yet to be determined. It seems fair to assume, from the foregoing experiments, that those particles which pass a 120 sieve, and are retained by a 180 sieve, very nearly approach that point; for, notwithstand-

FIG. 54.

ing the severe treatment to which they were subjected, to remove any trace of adhering flour, they developed nearly 60 per cent. of the strength of the original neat cement at twelve months.

The coarse particles being proved to have a certain value, it seemed a reasonable theory that their gradual incorporation and combination might prove to be responsible for the gradual increase in strength with age or growing power, which is the essential feature of a good cement, and

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therefore by extreme fine grinding, the cement merely attains its greatest strength in a shorter time, the ultimate strength of coarse and fine cement being practically identical. The table on page 206, which is taken from the same series of experiments,* shows the tensile strength and general characteristics of the four cements previously mentioned under the following conditions:—

1. As received from the manufacturer.

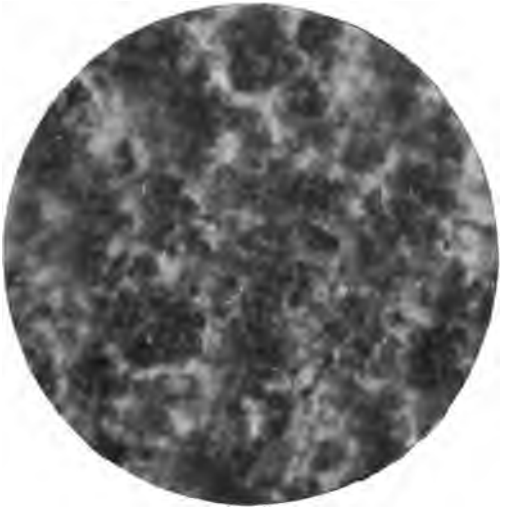

FIG. 55.

2. Re-ground so as to practically all pass a 180 × 180 sieve.

3. All particles that would not pass a 180 sieve extracted, and grains of sand of a similar fineness substituted.

Although the results support the theory previously put forward to a certain extent, they conclusively demonstrate the immense superiority in cementitious value of a finely ground cement over a coarse one. Briefly summarised,

* 'Minutes of Proceedings, Inst. of Civil Engineers,' vol. cxxxii. p. 346.

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Cement.	How Treated.	Fineness-residue per cent. on Sieves of Meshes per Lineal Inch.			Setting Properties.		Percentage of Water used for Gauging Briquettes.		Tensile Strength in lbs. per Square inch.									
									Neat Cement.					3 parts Sand to 1 part Cement.				
		180	76	50	Initial Set.	Set Hard	Neat.	Sand.	7 days	28 days	3 mons	6 mons	12 mons	7 days	28 days	3 mons	6 mons	12 mons
					mins.	mins.												
F	As received from manufacturer . . .	33·0	16·0	4·0	15	90	21·66	7·81	483	572	623	662	653	183	276	383	440	482
,,	Re-ground extremely fine	2·5	nil	nil	4	60	25·00	9·38	498	541	538	531	506	347	452	564	599	637
,,	All particles not passing 180 sieve removed and sand of similar size substituted . .	..	..	..	..	..	18·33	7·81	418	456	567	596	650	153	210	272	337	386
G	As received from manufacturer . . .	35·0	20·0	8·0	10	90	20·00	7·81	495	618	622	694	759	187	245	334	377	392
,,	Re-ground extremely fine	1·0	nil	nil	1	4	25·00	8·13	540	474	560	466	477	282	363	494	595	617
,,	All particles not passing 180 sieve removed and sand of similar size substituted . .	..	..	..	..	..	18·33	7·81	403	448	602	678	714	158	209	303	348	378
H	As received from manufacturer . . .	28·0	11·0	4·0	8	60	19·16	7·81	445	493	584	663	706	167	230	312	373	399
,,	Re-ground extremely fine	0·8	nil	nil	2	5	26·66	8·13	433	501	514	482	535	287	364	508	585	599
,,	All particles not passing 180 sieve removed and sand of similar size substituted . .	..	..	..	..	..	18·33	7·81	367	453	604	669	692	145	212	271	348	405
I	As received from manufacturer . . .	39·0	15·0	2·5	20	120	20·00	8·59	592	639	736	791	751	240	297	389	425	410
,,	Re-ground extremely fine	0·8	nil	nil	2	10	30·17	11·26	417	394	489	476	498	387	465	560	585	618
,,	All particles not passing 180 sieve removed and sand of similar size substituted . .	..	..	..	..	..	18·33	7·42	470	565	653	698	754	200	246	312	382	380

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they show that, by extreme fine grinding, its cohesive power is diminished, but its adhesive power or cementitious value —as demonstrated by its power of cementing together particles of sand—is immensely increased. The extraction of the coarser particles, and substitution of grains of sand, corroborates the opinion that the coarser particles have a slight though specific value, for in several cases both the cohesive and adhesive power of the material is diminished by their removal.

An instance of the latent cementitious value of the coarse particles in an ordinary cement briquette, was brought forward by Mr. G. L. Anderson in the course of a discussion on the author's paper on Kentish Rag admixture.* Mr. Anderson experimented with some briquettes about a year old, made of cement which had originally been ground to about 5 per cent. on a 50 sieve. He simply ground them up again, without any recalcination or other treatment, so as to all pass a 76 sieve and leave only 16 per cent. on a 180 sieve, and tried what strength could be got from the powder thus produced. He was astonished to find that he got results which would satisfy any ordinary specification, thus showing that the unexhausted cementitious energy in the residue itself was equal to the requirements of most specifications of the present day. The figures were as follows: Neat briquettes, 1 square inch section, stood, at seven days, 403 lbs.; at 28 days, 415 lbs.; at three months, 435 lbs.; at six months, 444 lbs.; at twelve months, 452 lbs. The three to one sand test was the most remarkable—at 28 days, 224 lbs.; at three months, 300 lbs; at six months, 404 lbs.; at twelve months, 432 lbs. These results show pretty clearly that the interior portion of the coarser particle is practically unacted upon by the water, at all events at the end of a year, and, upon being

* 'Transactions, Society of Engineers,' 1896.

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broken up fine enough, it performs the same function as the finer cement would do in the first instance. The results obtained from the neat briquettes, however, seem to corroborate the views just previously expressed by the author as to the gradual incorporation and combination of the coarser particles being responsible for the gradual increase in strength with age, since in this case the coarse particles have all been reduced, and the increase at the several dates of testing is abnormally small.

It must not be forgotten that, although a fine cement is undoubtedly of more value than a coarse one, fine grinding means increased expense to the manufacturer, and therefore for a specially fine cement he is entitled to a correspondingly higher price. Not only is it more expensive as regards consumption of engine power, etc., but it also reduces the output of the works ; finer grinding, therefore, from a manufacturer's point of view, means either expenditure of capital, in providing increased grinding plant, or reduction in output. Some ten years ago, when a cement leaving about 10 per cent. on a 50 sieve was considered a very fair commercial article, it was found that by reducing the fineness to 5 per cent. on a 50, to meet a special specification, the output of the millstones was reduced from about 1·33 ton per hour to barely 1 ton, or, in other words, to maintain the output, an increase of 33 per cent. in the grinding plant was required.

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CHAPTER IV.

TENSILE STRENGTH.

THE object of testing the tensile strength of cement is, primarily, to ascertain the strength which it will develop within a certain time, and, secondarily, by comparing the increase in strength between the different dates of testing, to enable some opinion to be formed of the ultimate strength likely to be attained by it. It is obvious that a cement which develops a moderate strength at the end of a week, and shows an increase of 25 per cent. at the end of twenty-eight days, is likely to attain a greater ultimate strength than one which shows say a 30 per cent. higher strain at seven days, and develops practically no increase at all at the twenty-eight days. The tensile strain, therefore, at one date only is not much of a criterion as to the value of a sample, and tests should be made at least at two dates, so that the "growing power" of the sample may be ascertained. The usual practice is to ascertain the tensile strain at three, seven and twenty-eight days from the time of gauging, and the increase in strength between those dates enables a fairly good opinion to be formed of the value of the cement.

In making briquettes for testing, much depends upon the skill of the operator as to the nature of the results obtained, and it should at once be distinctly understood that such work is that of a skilled operator, and should

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not, as is too often the case, be entrusted to an ordinary bricklayer's labourer. To quote Faija, in testing the tensile strength of a cement, "it must be premised that the object is to obtain the very best results possible, compatible with certain rules which custom has laid down, and which may therefore be considered as a fair test." With this the author fully concurs, and he maintains that the object of a laboratory test in this particular, is to ascertain what the cement is capable of under the most favourable conditions; a standard for comparison is thus created, and it is the user's duty to see that these conditions are fulfilled as nearly as possible in actual work.

In gauging briquettes for testing purposes, the first matter is to ascertain the percentage of water necessary to reduce the cement to the proper consistency for filling the moulds. This is done by weighing out a small quantity of cement, say five ounces, and adding water by degrees from a small graduated measuring glass until by continuous working with a trowel it is rendered plastic, and, on beating the mass into a small pat or cake, the water just rises to the surface when smoothed with the trowel. The quantity of water required to bring the cement to this condition varies with each sample, and no hard-and-fast rule can be laid down on this point. It will be found that if sufficient is added, so that, on ramming and shaking the cement into the moulds, the water just rises to the surface of the briquette, the best results will be obtained. Theoretically, a cement does not require more than 8 or 9 per cent. of water for the actual process of crystallisation, as briquettes of gauged cement examined some months after gauging never contain more than that quantity. It is, of course, impossible to make the particles of cement flux together properly with such a small quantity of water, and when the water just shows on the top of the briquette, it is

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an indication that just sufficient has been added to enable this fluxing to take place.

The disadvantageous effect of a large excess of water was realised as long ago as 1877, when Mr. Mann * published the following table, showing the results obtained by using various proportions of water :—

CEMENT GAUGED WITH VARIOUS PROPORTIONS OF WATER.

Age of Samples, seven days.

Average breaking weight per square inch.

—	5 oz. Water to 32 oz. Cement.	6 oz. Water to 32 oz. Cement.	7 oz. Water to 32 oz. Cement.	8 oz. Water to 32 oz. Cement.	9 oz. Water to 32 oz. Cement.	10 oz. Water to 32 oz. Cement.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
	433	460	..	306	..	..
	416	435	..	296	..	..
	416	480	..	282	..	..
	344	398	382	363	223	184
	368	366	387	357	219	221
	329	416	353	339	211	197
	487	489	323	316	187	163
	474	447	420	302	234	165
	440	471	336	268	209	162
Averages .	412	440	367	314	214	182

"With 5 oz. of water to 32 oz. of cement the gauged cement was extremely dry, crumbling under the trowel, and could not be made to take a smooth surface; with the proportion of 6 oz. to 32 oz. it was moderately dry, and could be finished and smoothed off with the trowel;

* 'Proceedings of the Institution of Civil Engineers,' vol. xlvii. p. 260.

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with 7 oz. to 32 oz. the mass was moderately wet; with 8 oz. to 32 oz. the samples were wet and soft; with 9 oz. to 32 oz. they had the consistency of stiff grout; and with 10 oz. to 32 oz. a liquid was produced which could be poured from one vessel to another. In the last two cases the sample shrank considerably, and must have lost some of the water by evaporation."

The quantity of water requisite also depends on the fineness and age of the cement, a fine cement requiring considerably more than a coarse one, inasmuch as the particles are in a finer state of division, and thereby are enabled to combine with a greater quantity of water. Why a well-matured cement should require more water than one freshly ground, is not altogether clear, unless it is that some of the coarser particles of the cement split up, through hydration by the moisture in the atmosphere, and thereby more readily combine with, and require more, water.

The shape of the briquette has more effect on the result obtained than is generally recognised, and a gradual improvement in the shape of the mould, so as to give improved results in testing, is rather a strong argument in favour of the contention that the object of testing is to obtain the best results from the sample under examination. The original form of briquette used is shown in Fig. 56; its rectangular shape was naturally a source of weakness, and the results obtained from it were often unsatisfactory. The method originally adopted in France, was to mould the blocks in a solid rectangular form, and, when they had attained the prescribed age, cut out recesses at the sides to receive the clips. Such a process is worthy of quotation, as illustrative of the very primitive methods of testing in use in the early days of the cement industry.

Fig. 57 shows a later form of briquette. Metal plates

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were inserted at the upper and lower side respectively the two square holes shown, on which rested the knife edg of the tension apparatus, and thus a fairly direct pull w exerted. The author had occasion to use this shape briquette at a works where no other was to be had, a obtained fairly good results from it; but it is too clum and cumbersome for general use, one briquette of 1½ by section requiring nearly 5 lbs. of cement.

Fig. 58 is the form originally adopted by Mr. Miche

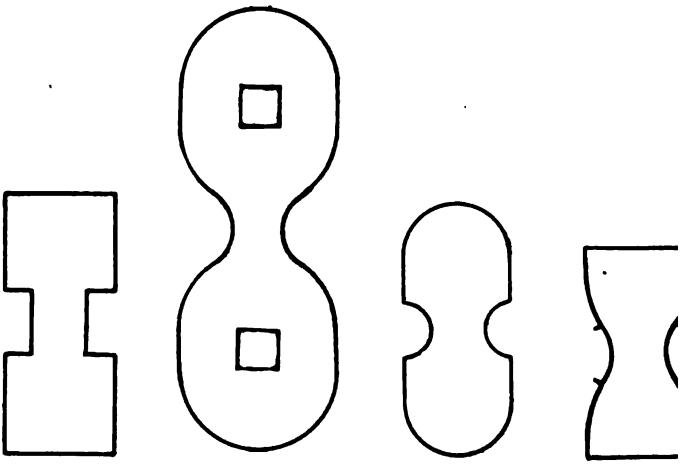

FIG. 56. FIG. 57. FIG. 58. FIG. 5

for use with his machine. The clips fit in the semicirc shown, and are practically in contact with the whole of surface. This form of clips and mould tend to exert crushing strain in addition to a tensile strain, and the resu are therefore not satisfactory; the briquette rarely brea at the smallest point of section, the line of fracture mc generally occurring in a diagonal direction.

Fig. 59 is the shape of briquette designed by the la Mr. Grant, and, with some modifications, is now in gene use. The briquette comes into contact with the clips at t

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points indicated in the illustration, and only at these points. The flat top of the briquette, however, exposes it to risk of damage in taking out of the mould, and, to obviate this, Faija adopted a modification which is shown in Fig. 60. By making the ends of the briquette slightly pointed, it is more easily removed from the mould without risk of damage, and the points of the apices serve in some degree to enable the briquette to be put squarely into the clips.

Fig. 61 shows the form of briquette in use on the Continent. It will be noticed that it has a notch in the centre, which ensures the fracture taking place at the point of

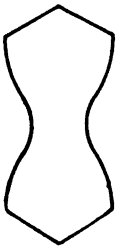

FIG. 60.

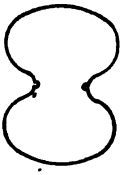

FIG. 61.

smallest sectional area; it seems a reasonable assumption, however, that the sudden reduction in the area of the briquette at that point would prove a source of weakness. The width of the briquette at the notch is 2·25 centimetres, which, with a thickness of 2·22 centimetres, gives a breaking area of 5 square centimetres.

With regard to the effect of the shape of the briquette on the results obtained, it may be interesting to quote the results of some experiments made by Mr. Bernays in 1881, which are given in the discussion on Mr. Grant's paper on Cement of that date.* "He wished to draw attention

* 'Proceedings of the Institution of Civil Engineers,' vol. lxii., pp. 207 and 20

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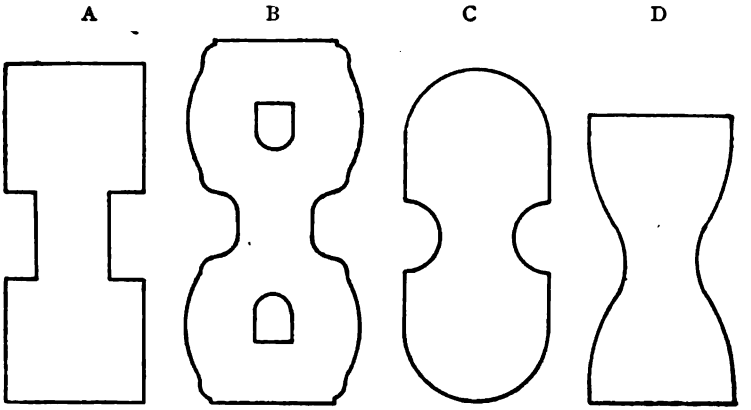
to a fertile source of misunderstanding, due to the omission to state, in most records of experiments on the tensile strength of cement, the precise form of briquette used. The greatly improved results, due to recent improvements in the form of briquette and of the breaking clips, went farther than was generally believed to account for the increased tensile strength of cement shown by recent tests over the results of experiments of earlier date.

"Since the reading of the papers on Portland Cement,



Mean breaking strain of six tests. Scale, ¼ full size.

FIG. 62.

he had made experiments with a view to determine, approximately, the variations in the tensile strain recorded by testing machines, due to the form of briquette adopted. The undermentioned results showed the average breaking strain, after seven days, of the same quality of cement made up into briquettes of the following forms :—

"It would thus be seen that the same cement was apparently stronger by 25 per cent. over form A when made

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into briquettes of forms B and C, and by 50 per cent. when tested by briquettes of form D. C represented the briquette used at Chatham; D that used by the Metropolitan Board of Works. A and B were formerly used at Chatham, but had long since been abandoned."

Generally speaking, all briquette moulds are constructed in two halves, which are held together by a suitable clip or spring. The original arrangement, however, with the form of briquette shown in Fig. 56, was for the mould to be all in

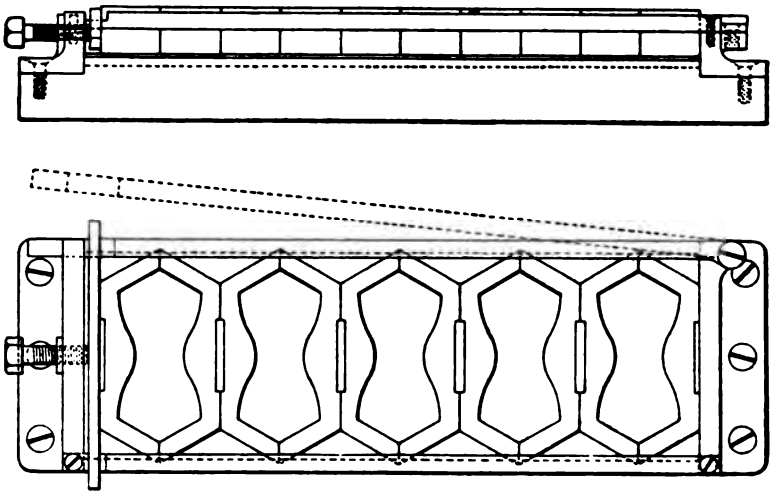

FIG. 63.

one piece, and the briquette, when partially set, was pushed out bodily by means of a die arrangement fitting over its surface. Needless to say, this method often resulted in the briquette being damaged, or at all events strained to such an extent that the resulting test was altogether misleading.

The great disadvantage of moulds that are held together by a spring is that they are liable to spread and open when the cement is being rammed and pressed into them, and thus the section of the briquette is distorted; it may be only

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slightly enlarged, but it is almost always unequally enlarged, so that the sides are not truly parallel, and consequently the clips do not fit properly, and exert an unequal strain. A very convenient arrangement of a nest of briquette moulds is that shown in Fig. 63, designed by the late Henry Faija. The corresponding halves of each mould are held in position by a small dowel at the apex, and each mould is firmly held down on the glass bedplate by two parallel square iron rods, (one of which is fixed and the other hinged at one end,) which fit into recesses cut into the moulds at their apex. A cross-bar and thumb-screw at one end of the nest hold them in position longitudinally. When the screw is tightened all the moulds are held firmly on the bed, which thus allows of the cement being thoroughly rammed and shaken, without any fear of deviation from their proper shape, or of lifting from the glass bed. To remove the briquettes, all that is necessary is to loosen the set screw, remove the cross-bar, swing out the hinged parallel-bar, and remove the moulds one by one on to a gauging slate or any plane surface, when, by gently tapping round the edges of the mould with the handle of a trowel, or any other convenient tool, each half of the mould comes away from the briquette and leaves it free. In this way there is no fear of any undue strain being put upon the briquette when freshly made, and therefore in such a state that the least injury will materially affect the result obtained from it. The convenience of such an arrangement will appeal strongly to those who are called upon to use single moulds that are merely laid on the bedplate, without being fixed thereto in any way; in making sand briquettes, especially, where the mass has to be beaten in with a trowel or spatula, the inevitable lifting of the moulds from the bedplate is a source of great annoyance. To prevent the cement adhering to the moulds, it is usual to slightly grease

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both the inner surface of the mould and the glass or iron plate on which it rests; care should be taken to avoid, excess of oil, only just sufficient being used to cover the surface of the mould with a thin film of grease.

In gauging cement for testing purposes, as well as in practical work, the chief object is to get it evenly and intimately mixed with the water in as short a time as possible before being put into the moulds, and, as previously stated, only sufficient water should be used to render the cement plastic. This entails a great deal of wrist work on the part of the operator, and, towards the end of a long series of

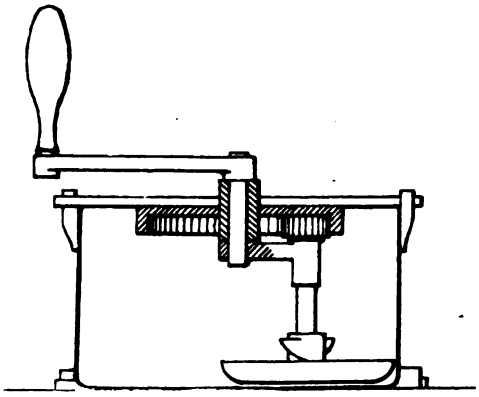

FIG. 64.

briquettes, he is apt to add more water than is absolutely necessary, with a corresponding diminution in results. To obviate this difficulty Faija designed a mechanical gauger, of which a sketch is given in Fig. 64. It consists of a circular pan, about one foot in diameter, within which revolve the arms of a stirrer. These arms revolve round their own axis in one direction, and around the pan in the reverse, this motion being given them by an internally toothed wheel, which actuates the pinion of the stirring spindle. The *modus operandi* is as follows: After having

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ascertained, by means of a preliminary hand-gauged pat, how much water the cement under treatment requires, sufficient cement to fill a nest of moulds is put into the gauger, and the correct amount of water added all at once. The handle of the machine is then turned fairly quickly for a half or three-quarters of a minute, by which time it will be found that the cement is thoroughly incorporated with the water, and the mass is in a proper condition to be turned out on to the gauging slate or bench and filled into the moulds. In gauging cement and sand in this machine, for making sand briquettes, it is of course necessary to first thoroughly mix the sand and cement in the dry state, after which the same routine may be followed. By the use of this machine two or three pounds of cement at a time can be efficiently gauged in a few seconds, and personal experience has proved it to be of the greatest value in avoiding the labour and wrist work necessary to bring the cement to a proper consistency with a trowel.

The whole operation of filling a nest of moulds, from the time of adding the water, should not exceed five or six minutes; and, after being smoothed off with a trowel, the moulds should be placed on one side until the briquettes are sufficiently set to be removed. With quick-setting cement this will generally range from one to three hours, but it is best, where possible, to make a rule of leaving the briquettes in the moulds for twenty-four hours, after which period, unless the cement is extraordinarily slow setting, there will be no danger of damaging them by premature removal; even then, however, sand briquettes will often be found very "green" and soft, and great care must be exercised that they are not damaged in any way.

Instead of smoothing the briquettes off level at the top, at the time of gauging, some operators prefer to leave the surplus cement until the briquettes are partially set, and

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then, by means of a sharp trowel, cut and scrape them off flush with the top of the moulds. The advantage of this plan is not easy to understand, unless it be that a slightly more accurate vertical thickness is obtained, while the chief danger is, that the setting of the whole briquette may thereby be disturbed, and consequently the result obtained less satisfactory. Care should also be taken, after the briquettes are gauged, to place them on a bench free from vibration, such as they would be subjected to if they were left on the same bench where subsequent briquettes were being gauged. If exposed to such vibration, the crystallisation or setting is materially affected, and the accuracy of the result considerably impaired. More than one instance has occurred of indifferent results, due to the neglect of this apparently obvious precaution.

The time previously mentioned as the time the operation of gauging should take, will of course depend upon the setting properties of the cement used, and refers chiefly to the gauging of a nest of five briquettes at one operation, which is the custom whenever the setting of a sample is sufficiently slow to permit of that course being adopted. If a cement commences to set or harden too quickly to allow of five briquettes being made at one operation, two or three only must be made, and great care must be taken that the cement does not commence to set before the operation is completed, otherwise the setting properties of the briquettes will be partially destroyed, and the results will be valueless. This quick-setting propensity can generally be overcome by spreading the cement out in a thin layer to aërate for a few days, by which means the aluminate of lime, which is the chief factor in the setting property of a cement, becomes air-slaked and its activity modified, and the cement thus rendered slower setting.

The gauging of sand briquettes is an operation requiring

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much more practice than neat briquettes, and with some operators it is a knack which cannot be acquired even by diligent practice. The cement and sand mortar, being considerably less cohesive than the neat cement, cannot be rammed so hard into the moulds; the effect of hard ramming is simply to press down the mass where struck by the rammer, while at the same time a corresponding quantity of the mortar is forced out at another part of the mould. From

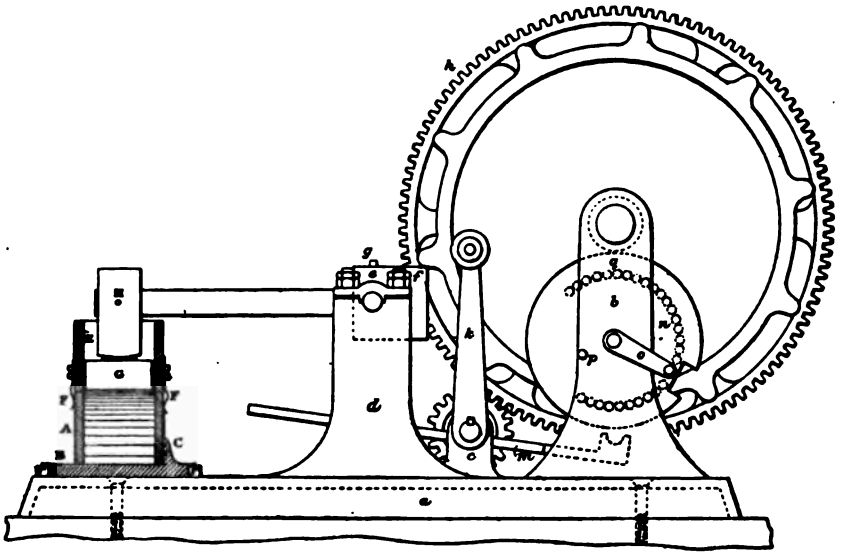

FIG. 65.

personal experience it has been found that the best method of making sand briquettes is to combine the operations of first ramming lightly with a wooden rammer, and afterwards beating in with a spatula or trowel, the beating being accomplished with a loose wrist, and the action being more of a "flip" than a direct blow. In the matter of water used for gauging sand briquettes, the same remarks apply as for gauging neat cement; no hard-and-fast rule can be laid down

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on this point, the best results being obtained when, after lightly ramming and beating with a spatula, as described, the water just shows on the surface of the briquette, denoting that there is just sufficient to lubricate the particles and enable them to flux properly into the interstices.

Although, as a rule, the ramming and filling of the moulds is performed by hand, mechanical means are occasionally employed. Fig. 65 shows Dr. Bohme's hammer apparatus for that purpose; it is largely used on the Continent, and, as will be seen on reference to the Appendix, is particularly specified in the German Standard Specification and Rules for Testing. For use with this machine the mould has a filling box E attached to it by spring clips F F. The sand and cement having been first thoroughly mixed dry, and then with the requisite quantity of water, a certain weighed quantity of the mortar is placed lightly, and as evenly as possible, into the mould and filling box, and the core G is placed on the top; by turning the handle *k* the mass is then struck a given number of blows with the hammer. The core and filling box is then removed, and the mass scraped off level with the top of the mould. As will be seen from the illustration, the end of the hammer handle is fixed into a rectangular casting, *f*, working on trunnions, and is lifted by coming into contact with the cog-like projections on the wheel *h*; each projection, as the wheel revolves, lifts the hammer, which falls and delivers its blow when the wheel has revolved far enough for the contact to be released. The number of blows delivered is regulated by means of a trigger arrangement, *m*, which prevents the wheel *h* from revolving any further when the required number of blows has been delivered. The author's experience of this machine is that the results obtained with it are generally inferior to the hand-made briquettes of a skilled operator.

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Unless the mortar is filled into the moulds and filling box very evenly, the core naturally has a tendency to sink lowest where there is least mortar, and thus getting slightly athwart the mould is liable to jam, and consequently the mass does not get the full benefit of the hammering. The mortar is also put into the mould all at once, with the idea of making the block of the same density throughout, but by this means there is a tendency for the upper part of the mass to be much more tightly rammed than the lower. With hand-made briquettes, on the contrary, the mortar is put into the mould in two or three lots, and each lot

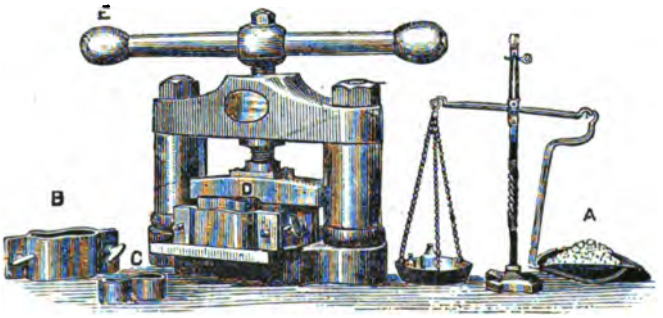

FIG. 66.

thoroughly rammed before the next is added. Compared with hand-made briquettes the operation is also rather tedious, as each briquette has to be operated upon singly, whereas by hand a nest of five briquettes can be filled at one time.

Fig. 66 shows the Arnold mould and screw press for making briquettes, etc., for testing purposes. Its essential feature is that the cement is pressed dry into the moulds, and then placed into a shallow tray of water to absorb as much as it requires for setting purposes. The mould B is made of such a depth that, after a weighed quantity of

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powder is placed into it, and the die C pressed flush with the top, the resulting briquette is of the desired thickness. Although this apparatus is still used in some testing rooms, the results are by no means comparable with the ordinary methods of making briquettes with the trowel, inasmuch as the thickness of the briquette depends entirely upon the bulk of the cement employed, a light cement being naturally much more bulky than a heavy one. As the method of incorporating the water is also entirely contrary to the methods usually adopted in the practical use of cement, it is decidedly less valuable as a comparative test. One advantage claimed for this apparatus is, that if the cement is at all inclined to be unsound, briquettes made in these moulds will show it more readily than briquettes gauged with the trowel in the ordinary way, inasmuch as the water attacks the free lime after the briquette is made, and thus causes marked expansion; whereas when mixing with the trowel, the water attacks the free lime during the operation of gauging and before the cement is formed into a briquette. The apparatus certainly has the advantage of not requiring skilled labour, as the briquettes can be made by any intelligent labourer, but, in the author's opinion, that is about the only point in its favour.

Standard sand, as it is now generally called, is Leighton Buzzard sand, thoroughly washed so as to remove any earthy impurities, and sifted so as to all pass through a sieve of 20 holes per lineal inch, and be retained on a sieve of 30 holes per lineal inch. This sand is supplied by a firm of pit-owners at Leighton Buzzard, ready washed and sifted to the standard size, but it is generally found advisable, in order to ensure accurate results, to have it re-washed and sifted in the testing room before use.

The use of the sand test, originally imported from Germany, is gradually making its way in this country, and

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doubtless, if a really reliable sand could always be obtained, the sand test would be of great value in forming an opinion of the constructive value of the cement, inasmuch as cement is never used neat, but always with a certain proportion of sand or aggregate, and its value, *quâ* cement, depends more upon its adhesive properties than its powers of cohesion. Faija was strongly averse to the sand test, his contention being that, in order to make a sand test of any value, it was first necessary to test the sand, and he advocated that, if a sand test were used at all, the sand to be actually used in the work should be utilised for testing purposes. This, of course, would afford valuable information to the actual user as to the strength of the work he was constructing, but it would only be of service on that particular work, and would be of no comparative value to anyone but himself. Until lately the author was naturally strongly imbued with the same views, but, as a result of recent experiments, he has been forced to the conclusion that a neat test by itself does not afford any true indication of the constructive value of a sample. In the course of his experiments on the effect of admixtures of Kentish Rag, etc., upon Portland Cement,* he found that it was possible to mix as much as 20 per cent. of foreign inert material, such as finely ground sand, with the cement without materially affecting the strength of the neat briquette, in some cases such an admixture actually improving it. The sand test, on the other hand, invariably showed the adulteration, although not to such an extent as to enable it to be detected by that means alone. In a later series of experiments on the finer grinding of Portland Cement, referred to on p. 206, it will be seen that an extremely fine cement is weaker when made into neat briquettes, than

* 'Transactions, Society of Engineers,' 1896.

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the same cement not so finely ground, although it shows nearly 50 per cent. greater cementitious value, as indicated by its power of cementing together particles of sand. In the face of those results, there is no doubt that the sand test is the truer test of the two, and it should therefore always be taken in conjunction with the neat test. The chief disadvantage of the sand test is the time required to enable it to be properly carried out, nothing under the twenty-eight days' test being of much value in this respect, and the delay thus incurred often renders it inconvenient if not impossible.

The machine used for testing the briquettes, or rather for measuring the strain which the briquette carries before fracture, is practically a weighing machine, and its chief desiderata are, accuracy, compactness and ease of working. Perhaps the most accurate machine is the long, single-lever, steelyard machine, in which the tension is applied by running a weight along the steelyard away from the fulcrum, and, by gradually increasing the leverage, the strain on the briquette is correspondingly increased. In using this machine, great care should be taken that the weight is run smoothly along the yard, as any swaying or vibration exercises an extra and undue strain upon the briquette. The steelyard machine of Messrs. Adie, which is illustrated in Fig. 67, may be had with an arrangement attached, by which the weight is automatically run along the yard, and the strain can thus be applied at any required rate of speed.

A somewhat more complicated, but decidedly less cumbersome, and more compact machine, is the compound lever machine of Dr. Michaelis, of which an illustration is given in Fig. 68, and which is now adopted as the standard machine in Germany. It consists of a double set of levers working on knife edges, and the strain is applied by allow-

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ing shot to gradually run into a receptacle hanging on the end of the upper lever. The shot falls into the receptacle from a reservoir fitted with an automatic cut-off, which stops the flow immediately the briquette breaks. The can containing the shot is then placed on a spring-balance weighing machine, which is scaled to show the strain in pounds at which fracture occurs. With this machine, also, it is important that the can should hang steadily on the end of the lever, and also that the shot should run into it in a

FIG. 67.

steady stream. The author has had considerable experience of this type of machine, and with careful usage it gives very satisfactory results; the knife edges of the compound levers, however, are rather delicate and require careful cleaning and attention.

Fig. 69 shows the bent lever machine patented by Mr. Michele in 1870. At the end of the longer arm are two heavy weights; the shorter arm is connected to a worm

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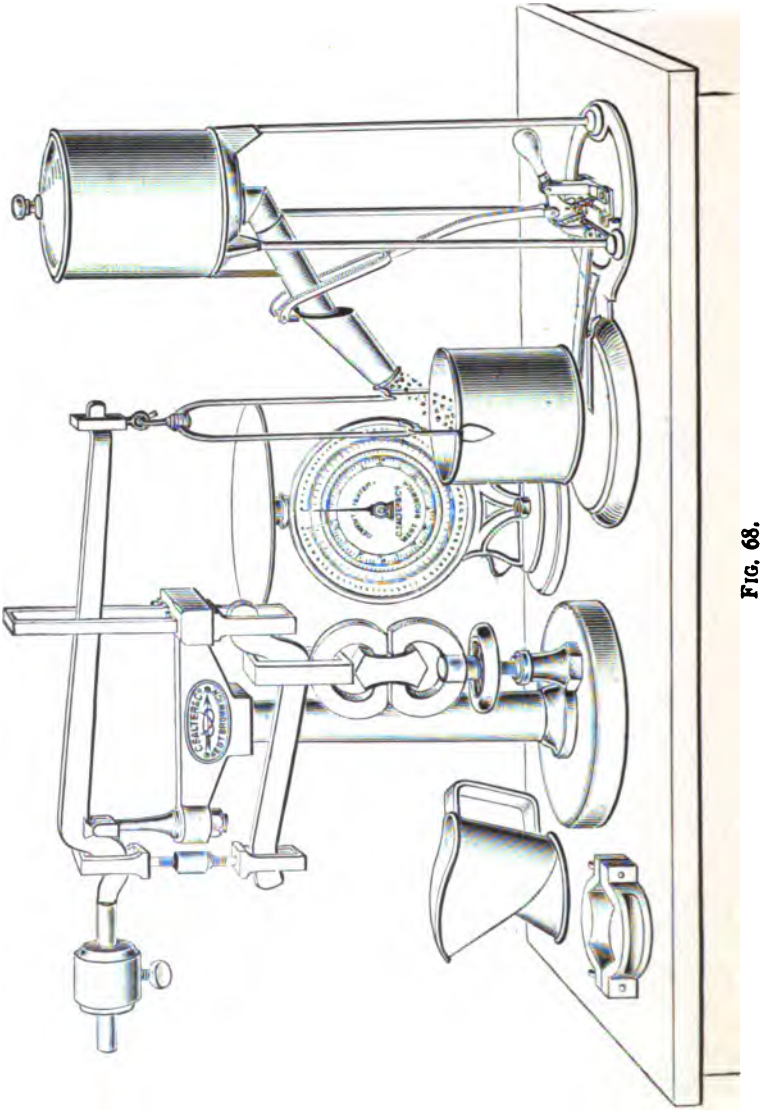

FIG. 68.

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and quadrant by means of the clips holding the briquette to be tested. On turning the handle of the machine, a

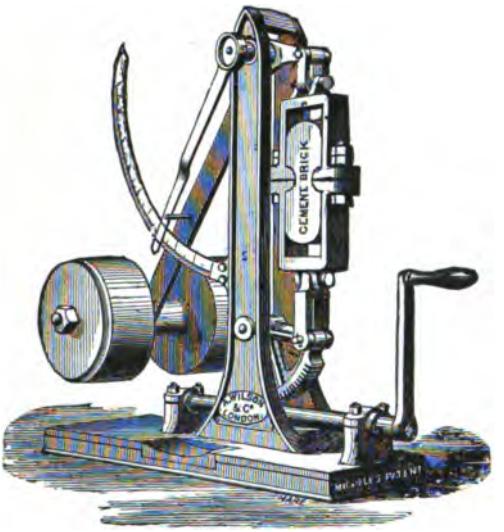

FIG. 69.

downward pull is transmitted through the briquette to the shorter arm, which lifts the weights on the longer arm, the tensile strain exerted depending on the height to which they are raised. A loose pointer is attached to the longer arm, and, by means of the scaled quadrant fixed in its path, indicates the strain at which the briquette breaks. In applying the strain, the handle should be turned steadily, without jerking, which would, of course, exert an undue strain on the briquette and tend to give a faulty result. Fourteen years later Mr. Michele patented the improved arrangement shown in Fig. 70, by which he dispenses with the worm handle and quadrant for applying the strain, and substitutes for them another lever and pair of weights; these weights are slightly heavier

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than the test weights, so as to give a preponderance for applying the strain to the briquette. To render this machine automatic in its action, a pinion and rack are attached to the heavier lever, which latter is connected to the piston of an oil cataract. By means of a valve arrangement, the flow of oil is controlled, and thus the speed at which the strain is applied can be regulated to any desired rate. Mr. Michele advocates that the speed

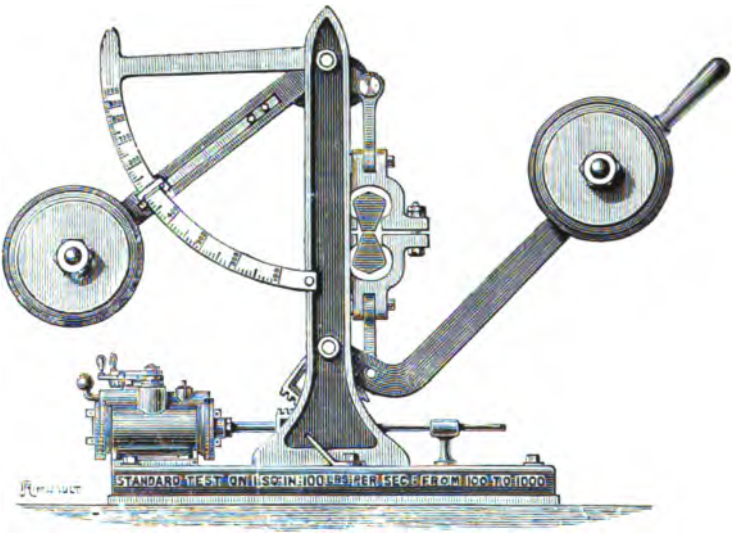

FIG. 70.

should be applied as quickly as possible, and his machine bears the inscription that the standard speed is 100 lbs. per second. With this the author cannot agree, for, as shown hereafter, by this means a much higher result is obtained—in fact, a delusive result, and one that no engineer or user would accept. With all due deference to Mr. Michele, the standard rate of speed is 100 lbs. in fifteen seconds.

Fig. 71 shows a very compact and handy machine in-

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vented by the late Henry Faija. It consists of a simple ten-to-one lever, on one end of which is attached a spring balance, and on the other end the clips holding the briquette to be tested; by exerting a pull on the spring balance, by means of a worm and quadrant, the strain is transmitted to the briquette, multiplied by the leverage of the lever. The knife edges at the balance end of the lever are lengthened, so that when the briquette breaks, the recoil

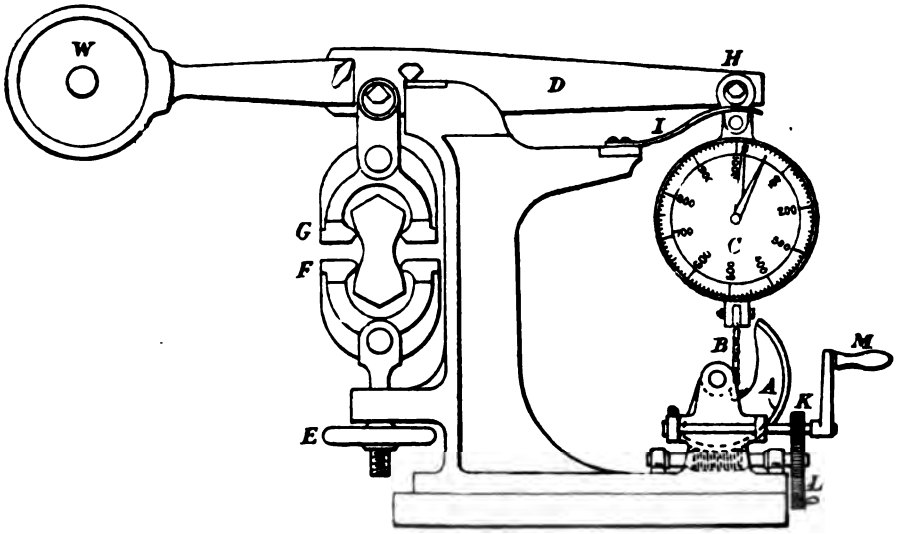

FIG. 71.

of the fracture is received by two suitably arranged buffer springs. The knife edges and all working parts are of specially prepared phosphor-bronze, and the gearing is so arranged that the strain may not be put on the briquette at too great a speed.

Before putting a briquette in the clips for testing, the quadrant A should be in the position shown, so that the chain B to the dial C is slack, and the lever D free and

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balanced; there should then be about half an inch between the under side of the knife edge H and the buffer spring I.

After inserting the briquette in the clips, the wheel E is turned from left to right, which will hold the briquette firmly, and it is generally advisable to put such a strain on the briquette by turning wheel E that about 100 lbs. is indicated on the dial. The handle M is then turned until the briquette breaks, and the loose pointer will show on the dial the strain in lbs. at which fracture occurred. To return to zero, the pinion K is thrown out of gear with the wheel L, by turning the pin and pushing the spindle to the left; the wheel L is then turned from left to right until the quadrant A has returned to its normal position, and the machine is then ready to receive the next briquette.

It may be as well to mention here that the buffer springs are only intended to take up the recoil after the briquette breaks. As an instance of the intelligence that is sometimes brought to bear in using machines of this kind, cases have occurred in which the under part of the knife edge (which, in the ordinary course, should only come into contact with the spring *after* the briquette has broken) has been allowed to rest upon it during the testing of the briquette, and consequently the greater part of the strain exerted has been on the spring instead of on the briquette. Owing to the slight give of the clips on the briquettes, the end of the longer arm of the lever is necessarily slightly depressed as the strain increases, but if about an inch space is left between the knife edge and the spring at the commencement of the operation, it will generally be found sufficient to keep them from coming into contact until fracture has occurred.

An objection is sometimes raised to the use of a spring

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balance in such machines, but these balances are specially made for the purpose, and are carefully tested before being sent out. The working parts of the machine are so arranged that, by simply taking out a screw and a split pin, the balance can be detached and checked by hanging dead weights upon it. The lever being ten to one, ten pounds dead weight should indicate one hundred pounds on the balance, etc. The author has had one of these machines in daily use for some years, and, in addition to periodically checking the accuracy of the balance, he also makes a point of having the whole machine tested two or three times yearly, by hanging dead weights up to 1000 lbs. in the clips of the machine, and the error rarely exceeds 1 per cent.

In testing for tensile strain, a great deal depends upon putting the briquette perfectly square and true into the clips or jaws of the machine, so that the strain exerted may be truly vertical and tensional, without any torsional strain. To ensure this, great care should be taken, firstly, that the sides of the briquettes where in contact with the clips are truly parallel, and also that the clips are accurately finished so as to exactly fit the briquette. With the Faija form of mould and testing machine, the points of the contact of the upper and lower clips on the briquette are about an inch apart ; the actual breadth of the contact is a little more than half an inch, and each should be exactly in the centre of the briquette, viz. $\frac{1}{4}$ inch from each edge. The clips of the machine are one inch in breadth, so that when the briquette is placed vertically in them, it is flush with the edges of the clips both back and front ; and if the top and the bottom edges of the clips F and G are at the same time parallel, as shown in the sketch, it indicates that the briquette is set truly vertical and square in them. If the operator has

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reason to doubt the accuracy of the moulds, or the fit of the clips, a very superficial examination of the points of contact of the clips on the briquette after breaking will prove the correctness or otherwise of his suspicion. If the briquette has been put properly into the clips, and the clips fit properly, the centre of each point of contact will be central vertically and also parallel horizontally. It may be thought that the author is somewhat hypercritical as to the exact fitting of the clips and briquette, but, so far as his experience goes, it is exactly these unconsidered trifles which make or mar the result. It has more than once been his experience to find one briquette out of a set of five break 25 per cent. below the rest, and on examination the only fault to be found with it was, that owing to the mould or the operator being at fault, the clips did not catch exactly vertically, thus giving an erroneous result.

The speed at which the strain is applied also largely affects the result obtained, and this is a matter which scarcely receives the attention it deserves. It was very prominently brought under the author's notice some twenty years ago. A dispute arose as to the tensile strain of a certain consignment of cement, and the briquettes made for testing were to be broken in the presence of the manufacturer. A Michele machine was then in use, and the manufacturer insisted upon applying the strain as quickly as possible, viz. about 100 lbs. in one second, with the result that a considerably higher tensile strain was developed than under ordinary conditions. This led to a series of experiments being instituted in the matter, which the author carried out under the late Henry Faija's directions ; the results were published in the 'Proceedings of the Institution of Civil Engineers,' 1883, from which the following extracts may be of interest :—

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"SUMMARY OF RESULTS OF EXPERIMENTS TO DETERMINE THE DIFFERENCE OBTAINED BY APPLYING THE WEIGHT TO THE BRIQUETTE, WHEN TESTING FOR TENSILE STRENGTH AT DIFFERENT SPEEDS.

Number of Briquettes.	Speed.			Average result.
	lbs.		secs.	lbs.
129	100	in	1	560·75
129	100	„	15	506·43
145	100	„	15	452·20
145	100	„	30	430·96
90	100	„	30	417·27
90	100	„	60	403·05
40	100	„	60	416·75
40	100	„	120	400·87

"From the foregoing results it will be seen that the increase per cent. due to increased speed in applying the strain is as follows:

"Taking the lowest speed of 100 lbs. in 120 seconds as a starting-point, by applying the strain at the rate of—

100 lbs. in	60	seconds	the increase is	3·960	per cent.
„	30	„	„	7·488	„
„	15	„	„	12·416	„
„	1	„	„	23·142	„

"From these results the accompanying curve of fracture (Fig. 72) has been obtained."

It will be seen that nearly 25 per cent. difference may be obtained by applying the strain at an extremely quick or extremely slow speed. The rate adopted by Faija as the outcome of this experiment was 100 lbs. in fifteen seconds, and that rate of speed is now very generally used. Variable rates of strain speed are sometimes specified by

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engineers, some even specifying that the briquette is to carry a certain weight for a specified number of minutes or hours. The advantage of such a hanging strain is a trifle obscure, and it is certainly very tedious to an operator who has a great many briquettes to break daily, to have to leave a briquette in the machine for any considerable length of time, thus taking several hours to accomplish what might have been done in almost as many minutes. Granting that such a test is considerably more severe than when the strain is gradually applied in the usual way, the author respectfully submits that the same purpose would be accom-

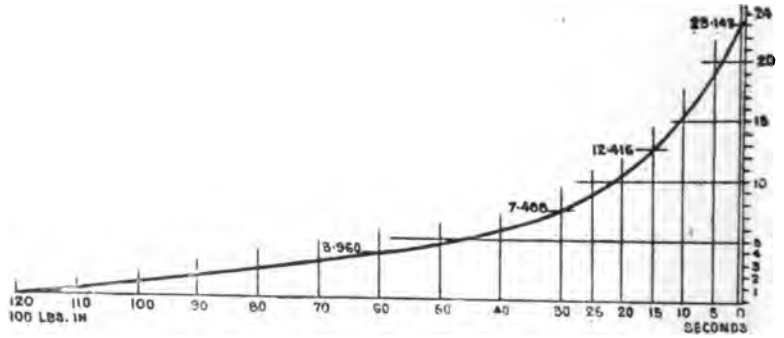

FIG. 72.

plished by proportionately increasing the strain to be carried, and having it applied at a reasonable rate of speed.

In testing a cement for tensile strain a great many factors come into play to produce a variable result, and it is therefore necessary, in order to obtain a fairly true result, to take the average of several experiments. It is the general custom to take an average of five briquettes at each date, and for this purpose moulds are arranged in nests of five. Why five briquettes, all made at one operation by the same operator, should show the variable results they often do, is not very easy to explain, except perhaps on the principle that it is impossible to make two things exactly alike. It is

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AVERAGE OF FIVE BRIQUETTES IN EACH CASE. The briquettes were placed in water twenty-four hours after gauging, where they remained until due for testing, when they were broken in a Faija machine, the strain being applied at the rate of 100 lbs. in fifteen seconds.

No.	Per cent. of Residue on Sieves having holes per Lineal Inch.					Water used for Gauging, Per Cent.		Time of Set in Minutes.		Soundness (Pats treated in the Faija Apparatus)	Tensile Strength in lbs. per Square Inch.				
											Neat Cement.			3 parts Sand to 1 part Cement.	
	50	76	100	120	180	Neat Cement.	3 of Sand to 1 of Cement.	Initial Set.	Set Hard.		3 days.	7 days.	28 days.	7 days.	28 days.
1	·4	1·0	6·0	..	..	17·50	8·33	120	510	V.S.B.	456	815	875	304	370
2	·6	2·0	6·0	..	..	16·66	8·33	60	300	Sound	536	691	738	249	291
3	·2	·6	2·0	..	..	16·66	8·33	12	330	„	732	900	939	313	410
4	..	trace	·6	..	..	21·66	8·33	15	45	„	416	531	667	199	280
5	·2	·6	4·0	..	..	17·50	8·33	30	60	„	510	663	699	223	266
6	·4	1·0	6·0	..	23·0	15·32	8·33	10	60	„	..	499	537	145	241
7	nil	trace	·4	..	6·0	16·66	8·33	30	450	„	..	998	943	379	469
8	·4	1·0	5·6	..	..	19·79	8·03	5	30	„	522	561	609	209	302
9	..	2·0	6·0	..	22·0	16·66	8·33	20	180	„	591	712	625	245	279
10	nil	trace	2·0	..	6·0	16·66	8·33	80	480	„	918	1025	1044	388	431

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probable that the discrepancy is more likely due to minute differences in the shape of the mould and fit of the clips than anything else, as it has been found that a very slight variation from a true vertical pull will materially affect the result obtained. Given that the object of testing for tensile strength is "to obtain the very best results possible," and thus ascertain what a cement is capable of under the most favourable conditions, it seems logical to suggest that, instead of taking the average of five briquettes, the highest result of five should be taken as a criterion, as that indicates what the cement is capable of, and, correct dimensions of the sectional area being premised, indicates the true strength of the cement.

The tensile strength of cement gauged neat usually averages about 350 lbs. to 450 lbs. per square inch at three days; 450 to 550 lbs. at seven days; and 550 to 650 lbs. at twenty-eight days; gauged with three parts by weight of standard sand, the tensile strength ranges from about 150 to 250 lbs. at seven days and 250 to 350 lbs. at twenty-eight days. The tensile strength of the sand briquettes compared with the neat briquettes depends entirely upon the fineness to which the sample is ground. The finer the cement the greater is its covering power, and consequently the greater is the tensile strength developed when mixed with sand. As will be seen on reference to the Table on p. 206, the strength of the sand briquettes may be nearly doubled by extreme fine grinding.

The table on the preceding page, giving the tensile strain, etc., of ten different cements, taken indiscriminately from our testing books during the past year, may be of interest.

For comparison with the foregoing, the two following tables (pp. 239 and 240), taken respectively from Grant's paper of 1881 and Faija's little treatise 'Portland Cement for Users,' are interesting chiefly as showing the improve-

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TABLE SHOWING THE SPECIFIC GRAVITY, WEIGHT, FINENESS, AND TENSILE STRENGTH OF TEN DIFFERENT CEMENTS TESTED, neat and with three parts of standard sand; showing the importance of fineness when the cement is mixed with sand.*

No.	Specific Gravity.	Weight per Bushel.	Residue on Sieves.			Water by weight per cent.	Neat Cement set in Minutes.	Neat Test. Tensile strain in lbs. per sq. in. in Weeks.						Sand Test. 3 parts Sand to 1 part Cement. Tensile strain in lbs. per sq. in. in Weeks.					
			50	76	180			1	4	13	26	39	52	1	4	13	26	39	52
			A. p. c.	B. p. c.	C. p. c.														
1	3·193	118	6·7	..	..	18·5	Slow	558	674	815	..	..	825	..	62·3	132·7	127·5	130·4	161·7
4	3·160	118	8·3	..	..	22·5	„	502	558	716	..	..	..	..	158	212	..	..	..
8	3·153	116	8·2	..	..	22·5	„	487	603	685	..	..	..	..	106	148	..	..	..
13	3·140	126	6·0	29·0	.	20·0	600	614	731	846	848	844	813	..	71	90	89	107	123
15	3·127	118	3·0	17·0	..	20·0	480	626	660	824	761	809	718	..	85	92	111	112	113
17	3·120	112	9·0	..	.	22·5	..	509	548	808	..	765	755	..	163	222	225	273	247
19	3·11	118	19·0	..	..	22·5	..	422	728	793	783	796	747	..	133	165	260	212	203
28	3·064	113	18·0	36·0	46·0	23·75	Quick	396	437·5	8 weeks 538·5	..	..	..	..	122·9	8 weeks 145·6	..	..	..
30	3·049	107	12·0	31·0	41·0	23·75	240	536	672	13 weeks 730	..	..	..	..	142·9	13 weeks 213·5	..	..	..
31	3·04	..	24·6	..	..	22·5	20–60	551	718	825	..	..	..	..	121	179	..	..	..

* 'Proceedings of the Institution of Civil Engineers,' vol. lxii. p. 169, and following. Mr. Grant, Extract from Table No. 47.

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TENSILE STRENGTH OF FIFTEEN SAMPLES OF CEMENT AT VARIOUS DATES.—Average of 10 Briquettes in each case. Mr. Henry Faija.

No. of Sample.	Weight per striked bushel.	Specific Gravity.	Residue per cent. after sifting through Sieves Nos.			Percentage of Water used in Gauging.	Placed in Water Hours after Gauging.	Remarks on time taken to set, &c.	Broke at lbs. per square inch of section at . . . days from gauging, having remained in water the whole time.					
			25	50	75				7	28	91	182	273	365
1	116	3·09	2	16	..	16·78	17	Slow	509	650	..	886	860	910
2	118	2·99	4	28	37	17·42	3	Quick	605	670	770	..	..	..
3	111	2·89	½	21	32	18·92	3	Quick	510	647	716	772	..	787
4	111	2·90	7	30	..	17·95	2	Very Quick	701	718	728	700	..	..
5	115	3·03	4	26	..	16·88	18	Slow	589	764	901	..	..	..
6	104	2·91	1	16	26	17·95	17	Very Slow	403	539	694	746	800	868
7	113	2·92	0	11	23	18·92	3	Quick	436	653	720	780	..	..
8	..	2·88	0	9	22	20·00	3	Quick	411	544	595	615	..	..
9	112	2·97	0	18	25	17·24	21	Slow	512	619	664	848	..	..
10	110	2·90	1	21	31	17·81	17	Slow	332	401	..	460	..	..
11	..	2·92	4	20	29	16·67	5	Quick	633	728	740	790	..	..
12	..	2·965	1	17	27	17·81	16	Medium	548	653	715	..	762	..
13	111	2·99	3	24	35	16·67	22	Slow	505	696	752	..	..	..
14	..	2·95	0	6	19	18·37	18	Medium	588	757	782	801	..	..
15	116½	3·00	0	14	30	18·42	16	Medium	476	656	700	..	..	..

ment in grinding and the consequent improvement in the sand test compared with Grant's figures.

Tensile strength, being the most easily applied test, is generally taken as the criterion of value, though it is doubtful if cement is ever subjected to that strain in actual use; the more usual strain is either a crushing strain or transverse strain, and some users therefore prefer to ascertain the power of resistance of a cement to these forces.

In testing a cement for resistance to a compressive force, cubes of specified dimensions are used, moulded in the same manner as the briquettes, and the remarks there-

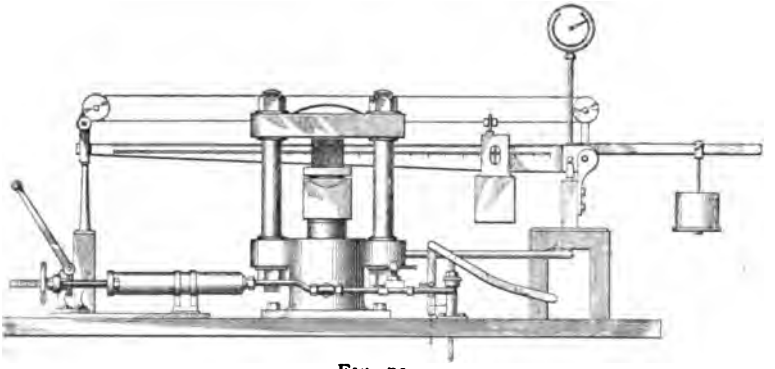

FIG. 73.

fore that apply to the gauging of cement for briquettes, apply also to the making of cubes. As the crushing stress of a cement is usually about ten times its tensile strain, the machine for testing has to be considerably more powerful than that used for tensile tests. Fig. 73 gives a sketch of a very convenient arrangement of crushing ram devised by Faija, and which the author has used for some years with satisfactory results. When the cube has been placed in position, the ram plunger is raised by means of the pump on the right, until a moderate pressure is exerted; in fact, the pump is merely used as a rough adjustment. The valve

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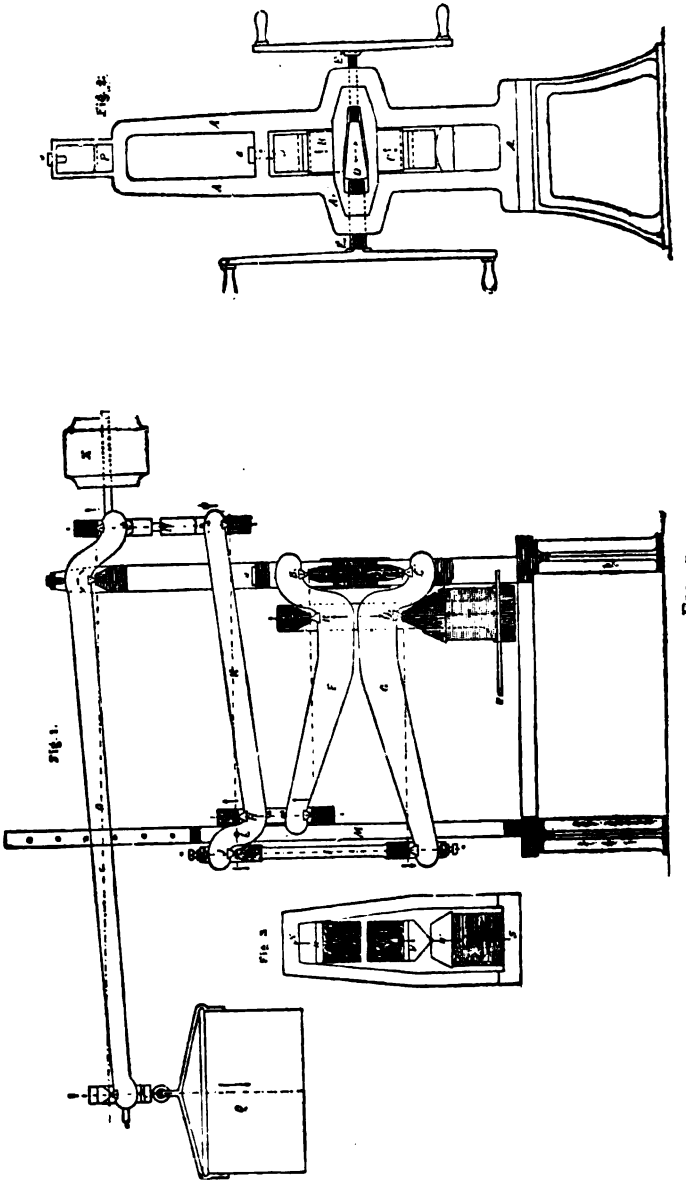

FIG. 74.

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between the pump and the ram chamber is then screwed down, and further pressure applied by means of the horizontal piston and cylinder arrangement shown on the left. It consists of a narrow piston with a cup leather attached, working in a solid brass cylinder. The piston rod has a Whitworth thread cut on it for the greater part of its length, and is forced into the cylinder by means of a specially designed screw-jack arrangement shown. For high pressure it was found impossible to work the jack wheel direct, and it was therefore arranged so as to be actuated by means of a worm and quadrant, worked by a handle about 18 inches long to give sufficient power. The crushing ram is 4 inches in diameter, and there is sufficient space between the holding-down bolts to admit a 9-inch specimen. A 3-in. cube is shown in the machine supported by a packing block with a ball-and-socket top, which adjusts itself to any slight inaccuracy in the shape of the cube, and thus ensures the strain being applied evenly over the whole surface. The apparatus is capable of exerting a pressure of about 40 tons. Connected to the ram chamber is a pipe leading to the small ram at the back, which actuates the long scaled lever shown. As the pressure increases, the lever is kept just balanced by means of a carrier containing a given weight, which is run along the lever and indicates the pressure at which fracture occurs. A Bourdon pressure-gauge is attached to the apparatus as a check on the accuracy of the measuring arrangement. With this apparatus it is usual to use 2-inch and 3-inch cubes; 1-inch cubes may of course be tested in it, but with the larger cubes the ratio of error is considerably diminished.

The Schickert multiple lever machine, shown in Fig. 74 is considerably used on the Continent for determining compressive stresses. It will be seen from the illustration that it is a combination of levers, the stress being applied by

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gradually weighting the can slung at the end of the first lever; the whole apparatus, with some necessary modifications, being an elaboration of the Michaelis tensile machine.

The Amsler-Laffon hydraulic press, illustrations of which are given in Figs. 75, etc. is considered by many to be the best arranged apparatus for crushing-tests. The machine consists essentially of an hydraulic press, as shown, in which the cylinder for applying the pressure is on the right, and the large cylinder carrying the ram is in the centre; the pressure of the hydrostatic fluid (oil), is imparted to a layer of mercury in the base of the ram cylinder, and is thence caused to support a column of mercury in the manometer tube (celluloid) shown on the left. The more important details are as follows: the barrel, or small cylinder, is filled with machine oil, and a screw plunger, actuated by the turning wheel and handle, causes the expulsion of the oil from this cylinder; a valve is fitted at the top to reduce the pressure if desired. In the bottom of the ram cylinder is a small piston, which is forced downwards out of the base of the cylinder by the pressure of the oil, and presses on a larger one immediately below. This larger piston has a lever attachment (to show its position), which projects in front, and by means of a second lever, actuated by an eccentric on the turning wheel, a slight oscillation is imparted to the piston, to keep it from sticking.

As this lower piston is depressed by the oil pressure, it presses on a layer of oil beneath, and then on a layer of mercury in the lower part of the cylinder. This mercury is in communication with the manometer tube, through a revolving tap at its lower end. An iron float rests on the mercury in this tube, and is balanced by a weight and cord running over a pulley, which is fixed with a ratchet wheel and pawl, to record the maximum height of the mercury. At the back of the ram cylinder is a small pump, and tubes

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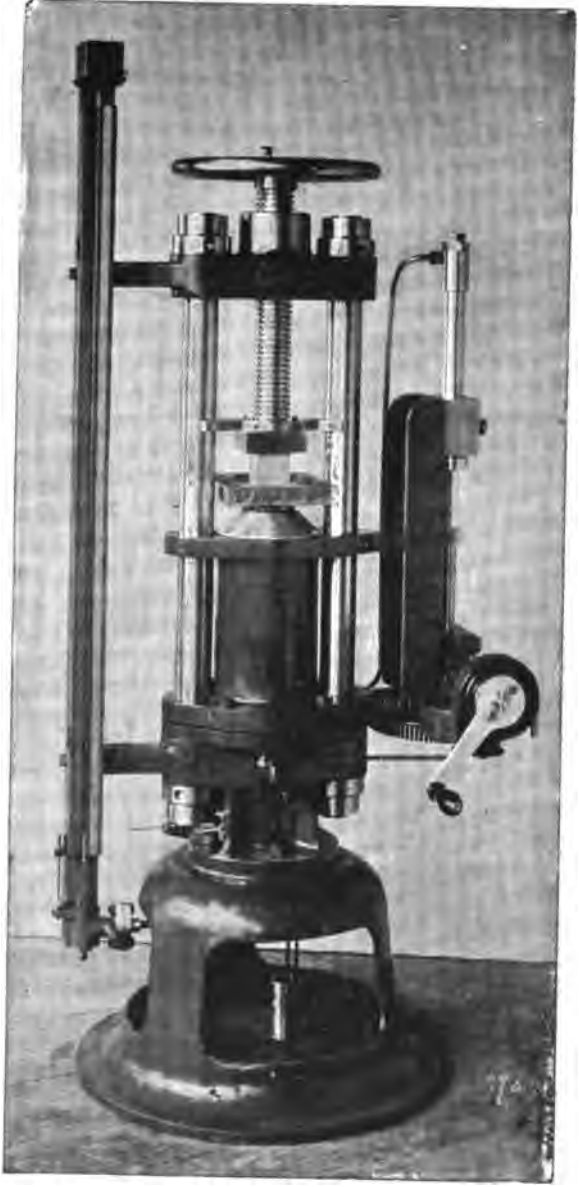

FIG. 75.

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which can be connected to the pump in turn, either during filling operations or when emptying for cleaning the mercury or working parts. The manometer is graduated with two scales, designed to work with a cube of 50 sq. cm. area of face: on the left hand scale the pressure is recorded in kilos. per sq. cm., i.e. the internal pressure of the oil in the cylinder; and on the right hand shows a total pressure of 100 kilos., i.e. the total pressure on the specimen. Extra fittings are also supplied, whereby this machine may be converted, if desired, into a tensile breaking machine.

The principal point requiring attention in testing a cube for compressive strain, is to make sure that the strain is distributed evenly over the whole of its area, for it is very evident that if the pressure first comes on one part of the cube only, it is crushed in detail, and a very erroneous result is obtained. To equalise the pressure as far as possible, and to ensure an equal distribution of the strain over the area of the cube, thin pads of soft wood are inserted between it and the surface of the testing machine, or the surface of the cube may be covered with a moderately thin coating of plaster of Paris for the same purpose. If the strain has been evenly and correctly applied, the sides of the cube commonly break away, leaving a true pyramid. It will be readily understood that the least inequality in the surface of the cube will make an immense difference in the result obtained, and for that reason the crushing test has not attained any great degree of popularity in England, though it is more generally used in Germany, and forms part of the standard tests in force in that country. Some experimenters who have experienced difficulty in working with cubes, have suggested that a cylindrical test-piece should be used instead of cubes, so as to avoid the corners, but the same objections present themselves, and it

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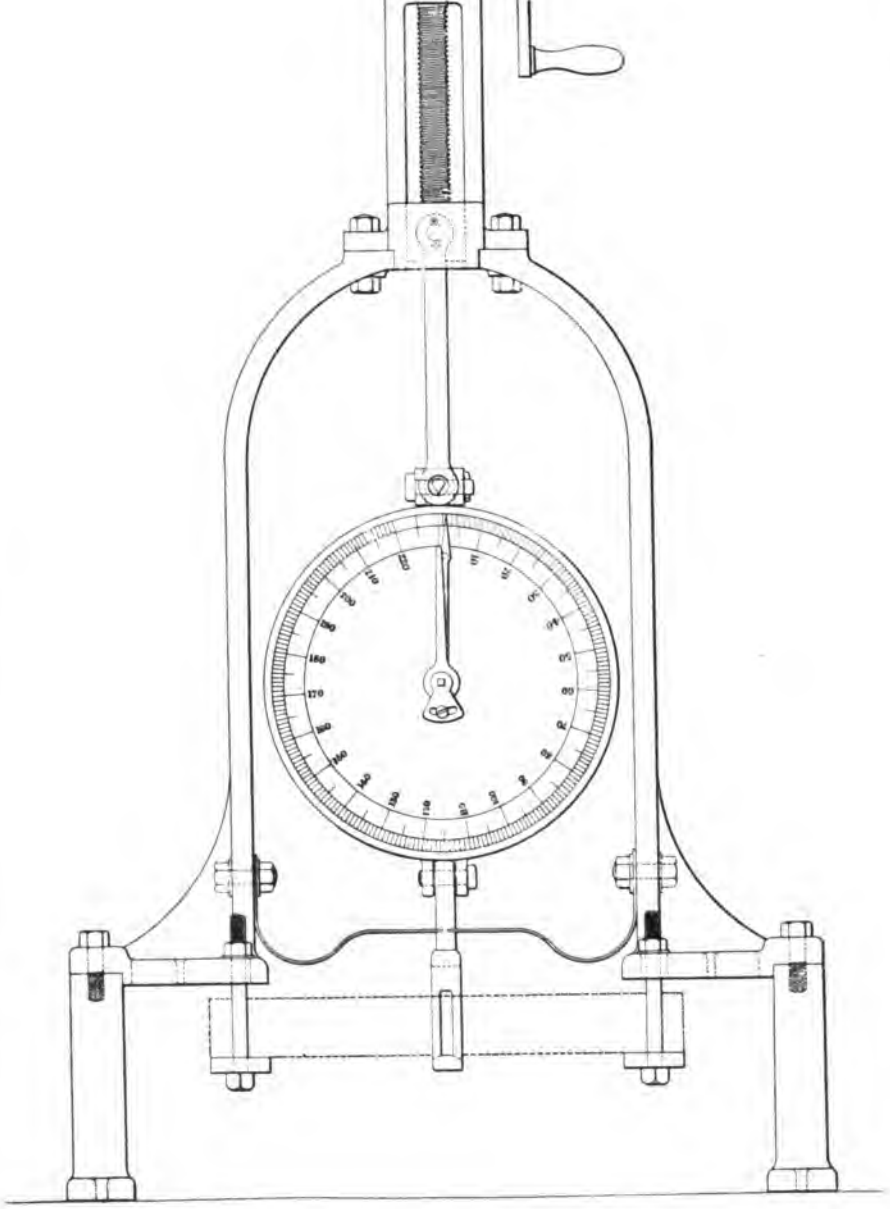

FIG. 76.

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is not easy to see in what respect their use would be an advantage.

The strain to which cement is more often subjected in actual work is a transverse one, which is really a combination of crushing and tensile strains, for if a prism or beam supported at each end is weighted in the centre until fracture occurs, the upper portion where the weight is applied is subjected to a crushing strain and the lower half to a tensile strain. To ascertain the resistance of cement to a transverse strain, it is sometimes specified that beams or prisms of cement, of one-inch sectional area, shall be supported at each end, and weighted in the centre until fracture occurs. To meet the requirements of a specification requiring such a test, the late Henry Faija devised the machine shown in Fig. 76, in which the prism is eight inches long, resting upon supports six inches apart. The strain is applied by means of bevel wheels actuating a vertical screw, which exerts a strain on the prism through the spring balance, on much the same principle as the Faija machine for testing tensile strength. As in the former machine, the dial of the balance is provided with a loose pointer, which stops when the prism breaks, and indicates the breaking strain. A sample of ordinary English manufacture, tested under these conditions some seven years ago, gave the following results, after seven days immersion in water as usual:—

	lbs.
No. 1 broke at . . .	85·5
„ 2 „ . . .	82
„ 3 „ . . .	95·5
„ 4 „ . . .	103
„ 5 „ . . .	98

Average, 92·8 lbs.

It is, however, a test that is very rarely asked for, only two or three instances having come under the author's notice.

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CHAPTER V.

SETTING PROPERTIES.

THE setting properties of cement are not of paramount importance, unless the sample is either abnormally quick-setting or abnormally slow-setting, except for tidal purposes and work of a similar nature, where it is requisite that the cement shall set sufficiently quickly to resist the action of the incoming tide, and so prevent the cement being separated from the sand or aggregate. The setting of cement may be conveniently divided into two periods, termed respectively the "initial set" and "set hard."

According to Le Chatelier, the setting of cement is caused by the formation of a super-saturated solution, which subsequently deposits crystals; the rapidity with which these crystals are formed and deposited, constitutes the rapidity or slowness of the setting of a cement. After adding water to a cement and reducing it to a suitable paste, a period arrives when the mass is no longer fluid or mobile; the water disappears from the surface, and it loses its shiny appearance. The period which elapses between the addition of the water and the moment when the mass loses its fluid condition is called the time of "initial set." With a quick-setting cement this period is very distinctly marked, the change of condition from fluid to solid, owing to the rapid formation and interlocking of the crystals, being readily recognisable. With a slow-setting cement, the change is very often so gradual as to be

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scarcely noticeable, and a great many of the slow-setting varieties of cement have no absolutely definable initial set.

The time of "set hard" is the time which a cement takes to acquire sufficient hardness to withstand certain pressure without leaving any indentation. The original method of ascertaining the time of set hard was simply to subject the pat to the pressure of the thumbnail, and when no appreciable indentation could be made, the sample was considered set hard. This test is decidedly of the rule-of-thumb order, but it fully serves its purpose, and it is doubtful if some of the more elaborate methods at present in use for determining the setting of cement are any material improvement. The thumb nail is an instrument that is always available for the purpose, and although of course the pressure depends to a considerable extent upon the muscular development of the operator, it affords a very good guide as to what is wanted. The method adopted by Faija for determining the time of set hard, was as follows: "A pat, gauged with the minimum of water, and placed on a glass slab, is subjected to a 'Vicat needle' every ten minutes, the needle being allowed to rest on it for one minute. When the needle makes no appreciable mark or indentation the sample is considered 'set hard.' The needle has a flat point of 0·1 inch diameter, and is loaded with a weight of three pounds."

Several users in this country have recently adopted some modification of the Continental method of ascertaining the setting time, which may be briefly described as follows: A circular brass mould, 8 cm. diameter by 4 cm. deep, resting on a non-porous bed, is filled with cement mixed with water to "normal consistency." The cement is considered to be of "normal consistency" when a plunger, 1 cm. diameter, and loaded to 300 grams, penetrates to

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within 6 mm. of the bottom of the mould. The period of the initial set is when a needle, having a sectional area of 1 mm., and weighted to 300 grams, will not penetrate to the bottom of the mould ; while the cement is considered set hard when the needle makes no appreciable indentation upon the surface of the cement.

The chief point of difference beween the above and the method adopted by Faija, is that the quantity of water required to obtain "normal consistency" is from 27 to 30 per cent., whereas the minimum of water as prescribed by Faija would be from 18 to 20 per cent., the smaller percentage of water naturally causing a quicker initial set.

It has been conclusively proved, in practice, that if cement is worked or manipulated after setting has commenced, its strength is very seriously impaired. This can be very readily explained. On adding water, whatever may be the action which takes place, it is very certain that crystals are formed, and when the initial set commences, and the mass is no longer fluid, it is an indication that these crystals have commenced to interlock. If now by overworking, or "killing," as it is generally called, these crystals are broken up again, their lock or bond is destroyed, and the strength and cohesion of the material correspondingly diminished. It is therefore of the greatest importance in practice that the cement should not be worked or manipulated after setting has commenced, and care should be taken that only such a quantity is mixed at a time, as can be thoroughly incorporated and placed in its allotted position before setting commences.

The setting of cement involving chemical action, it is, like most chemical actions, accelerated by heat and retarded by cold, and therefore a cement which has certain setting properties at the normal temperature of 60° F will have these properties considerably modified at higher

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or lower temperatures. This point was particularly referred to by the author in a recent paper,* from which the following is a quotation :—

"Temperature and climatic influences play a very important part in the setting of cement. The author's attention was particularly drawn to this matter a very short time ago. A shipment of cement, which had been tested in the ordinary course before leaving England, satisfactorily passed the requirements of the specification as to set, but on reaching its destination in a hot climate, the engineer in charge complained that it set too quickly. This induced the author to institute a series of experiments to ascertain the comparative time of set at different temperatures, the results of which are given in the following table. In each series of experiments an exactly similar amount of water was used for gauging, the water being of the same temperature as the chamber in which the pats were placed, and, to ensure a moist atmosphere the bottom of the chamber was lined with a damp cloth. The cements were not in any way chosen specially for this experiment, but have been arranged in the table according to their time of initial set. The difference in setting is distinctly marked at each temperature, more especially between 40° and the normal 60° F."

It is not an uncommon testing-room experience, especially during the summer months, to find that a rise of atmospheric temperature of three or four degrees during the morning, makes just sufficient difference in the setting of a sample to determine the possibility or impossibility of properly gauging and manipulating it. For instance, a quick-setting cement which at an atmospheric temperature of 60° F. allows just time to get the briquettes properly gauged and finished off before setting commences, would at a tempera-

* 'Transactions Society of Engineers,' 1895.

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Influence of Temperature on the Setting of Portland Cement.

Sample No.	Temperature Fahrenheit.							
	100°	80°	60°	40°	100°	80°	60°	40°
	Initial Set in Minutes.				Set Hard in Hours.			
1	1½	4	6	13	1¼	1½	2	2½
2	3	5	6	8	1	1¼	1¾	2½
3	4	10	15	20	½	¾	1½	6½
*4	5	9	15	30	½	¾	1	6
5	6	10	14	25	1	1½	2	2½
*6	7	12	15	20	1¾	2	2¼	2½
*7	9	10	15	17	3½	6	7	12
8	10	15	35	40	¾	1	1¼	1¾
9	11	15	20	57	3	5	6	10
10	11	13	15	30	2½	3	3½	6
11	19	32	60	120	3	6	7	15
12	15	35	70 *	360	3½	6	7	22

* Contain a considerable admixture of Kentish Rag.

ture of 64° F. commence to set a minute or so sooner, and thus preclude the possibility of its being properly gauged without some risk of injuring its setting properties. It occasionally happens, also, that a cement has such an extremely quick, though somewhat feeble initial set, that the operator is apt to work through it, without becoming aware of the fact; it is a very good rule when gauging pats for ascertaining the setting properties of a sample, to take about an ounce of cement and gauge a small preliminary pat, in about

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half a minute, with a large excess of water; by this means any such peculiarities would be readily detected, which in gauging a larger quantity in the ordinary way might be overlooked. Cases also occur sometimes in which the sample has a species of secondary initial set; the first one generally takes place within a minute or so of adding the water, but if the mass is continually worked with a trowel, this primary initial set may be worked through, and the water brought to the surface in the ordinary way; and then a secondary initial set manifests itself a few minutes later. It is not easy to explain these phenomena, but they are very probably due to the presence of a small percentage of sulphate of lime, or gypsum, which matter will be referred to later.

It is scarcely necessary to add that the quantity of water used for gauging materially affects the setting properties of a sample, an excess of water retarding, and very dry gauging accelerating, the time of set. Assuming Le Chatelier's supersaturation theory to represent the action which takes place, it is very evident that the more water added, the less quickly would the solution become supersaturated, and consequently the longer the period that would elapse before crystallisation, i.e. setting, commences; and *vice versâ* with a very small quantity of water. As stated previously, the minimum of water should always be used, so that, after thoroughly trowelling and beating the mass together into a pat, the water just rises to the surface.

As already mentioned in the chapter specially treating on that subject, the fineness to which a cement is ground largely affects its setting properties; the finer a cement is ground the quicker-setting it becomes, owing to the greater facility which is afforded to the water to combine with it. A cement that has an initial set of ten minutes when ground to what, up to within the last few years, was considered a

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well ground cement, viz. leaving about 10 per cent. on a 50 sieve, will be found to commence to harden within a minute or so, if ground so as to all pass through a sieve of 76 meshes per lineal inch. The table on p. 256 gives the result of some experiments, carried out by the author a short time ago, as to the effect of finer grinding on the setting properties of cement.*

In several cases it will be seen that finer grinding immensely accelerates the setting properties of the samples. Cement L, for instance, when ground to the ordinary degree of fineness, has an initial set of twenty-five minutes, and is set hard in forty-five minutes, while, when re-ground extremely fine, it commences to set within one minute of adding the water, and crystallisation proceeds at such a rapid rate that it is set hard in five minutes. No doubt the setting is accelerated in two ways: firstly, by the water being able to more readily combine with it; and secondly, by the heat evolved by the rapid crystallisation warming the mass, and thereby further accelerating its setting.

As has already been stated, the setting of cement is a process of crystallisation, and, like most processes of a similar nature, it evolves more or less heat, the amount of heat evolved depending upon the vigour and intensity of the crystallisation, or, in other words, upon the time which a cement takes to set. Until some twenty years ago, Faija made a rule of noting the rise of temperature of a cement during setting as indicating its setting properties. A greased thermometer was placed in the pat immediately after gauging, and the temperature noted. As the setting proceeded, the temperature was found to rise until a maximum was reached, the period occupied in reaching this maximum depending upon the setting properties of the sample. After the maximum was reached, the temperature was found to

* 'Proceedings Institution Civil Engineers,' vol. cxxxii., p. 350.

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Cement.	How Treated.	Fineness-residue per cent. on Sieves of Meshes per Lineal Inch.			Setting Properties.		Increase in Temperature during Setting.	Return to Normal Temperature.	Pat treated in Faija Apparatus for Soundness.
		180	76	50	Initial Set.	Set hard			
					minutes.	minutes.	°F. mins.	ms.	
J	As received from manufacturer	22·4	6·0	nil	25	45	22 in 40	120	Sound.
,,	Reground to pass 180 sieve	Trace	nil	nil	1	5	38 in 5	90	,,
K	As received	26·6	10·0	2·7	30	90	17 in 100	240	Sound.
,,	Reground as above	Trace	nil	nil	6	15	32 in 11	150	,,
L	As received	24·4	7·6	1·5	30	120	9 in 60	180	Blown.
,,	Reground as above	Trace	nil	nil	7	15	29 in 13	120	Sound.
M	As received	30·0	6·7	1·2	20	60	21 in 34	150	Sound.
,,	Reground as above	Trace	nil	nil	2	10	26 in 8	75	,,
N	As received	28·4	9·3	1·0	15	30	25 in 21	120	Sound.
,,	Reground as above	0·6	nil	nil	1	10	32 in 4	120	,,
O	As received	26·4	7·7	0·5	Undefinable	360	2 in 39	160	Sound.
,,	Reground as above	0·4	nil	nil	8	25	27 in 12	95	,,
P	As received	18·0	3·0	0·8	15	240	15 in 23	120	Badly blown.*
,,	Reground as above	0·4	nil	nil	2	240	23 in 5	100	Very slightly blown.*
,,	As received mixed with 2 per cent. gypsum	18·0	3·0	0·8	Undefinable	1440	1 in 15	35	Blown.*
Q	As received	34·8	16·0	3·6	20	30	17 in 35	180	Badly blown.
,,	Reground as above	1·6	nil	nil	2	5	26 in 5	180	Sound.
,,	As received mixed with 2 per cent. gypsum	34·8	16·0	3·6	Undefinable	1440	1 in 15	30	Blown.

* A specially prepared "overlimed" cement.

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gradually recede until the pat had returned to the original temperature. The time which elapsed between the addition of the water and the return to normal temperature was considered the time which a cement took to set. This test was shortly afterwards abandoned for the weighted needle test, previously mentioned, and very properly so; for, although the particulars of the rise in temperature during setting may afford very valuable information as to the primary setting properties of the sample, it is a little difficult to understand what relation the return to normal temperature bears to the period of set hard.

In his paper on the Vyrnwy Dam of the Liverpool Waterworks,* Mr. Deacon advocates the observation of the rise of temperature during setting as a test for free lime. He says:—

"It was required that the cement as delivered should be slow setting. In the earliest stages of the work the condition of such cement, as regards the presence of free or loosely combined lime, was determined by the old method of making thin pats and observing the degree of tendency to crack after many days, but this was subsequently abandoned for a perfectly simple and exhaustive test which could be made in a few minutes, and which the author has adopted ever since. A hand sample of cement, a small vessel of water, a marmalade pot and a thermometer are left together for a short time to acquire a uniform temperature. The cement is then gauged in the pot as quickly as possible, with just sufficient water to render it plastic, and, the thermometer being immediately pressed into it, the initial temperature is recorded. If within fifteen minutes the rise of the thermometer exceeds 2° F., or within sixty minutes 3° F., the cement is further exposed before use. No bin of cement was certified for use on the works until

* 'Proceedings Institution Civil Engineers,' vol. cxxvi., pp. 46, etc.

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it had passed one of these tests. This precaution, combined possibly with the comparatively dry method of manipulation already described, is so effective that where it has been adopted the author has never seen a hair crack of the kind so familiar where fresh cement is used."

In the discussion which ensued, the author challenged the utility of this test, and maintained that the rise of temperature during setting was rather due to the chemical action of crystallisation than to the presence of free lime, and it was chiefly to illustrate this point that the experiments quoted in the table on page 256 were undertaken. Referring again to that table, it will be seen that in each case the heat evolved bears a marked relation to the setting properties of the sample. As a general rule it was found that the thermometer was practically stationary until the period of initial set was reached, and then it commenced to go up rapidly; in some cases the activity of the crystallisation was so intense, that the temperature ran up 30° or 40° F. in five or ten minutes, and the heat generated caused some of the moisture to be given off in the form of vapour which could be plainly seen rising from the pats.

It will also be noticed that cements P and Q, which when coarsely ground are unsound and show a comparatively moderate increase in temperature, evolve much greater heat when finely ground, owing to their being quicker setting, and yet are perfectly sound. Cement L also gives similar results. To ascertain conclusively whether the presence of free lime, or the action of crystallisation was responsible for the rise in temperature during setting, cements P and Q in their coarse condition were mixed with 2 per cent. of gypsum, which it is well known retards the setting of cement. The result was that they were thus rendered extremely slow setting, and practically evolved no heat whatever, and yet they were still unsound,

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and developed decided indications of blowing in the Faija apparatus.

Later researches * have fully confirmed these results, which not only show that a cement which develops a considerable increase in temperature may be perfectly sound, but, what is more to the point, a cement may be extremely slow setting, and therefore show no rise of temperature whatever, and yet be absolutely unsound and unfit for use. Such a test, therefore, while it certainly ensures an extremely slow-setting cement, which in view of the special method of manipulation adopted by Mr. Deacon was absolutely imperative, in no way guards against an unsound one, and moreover imposes needless and irritating restrictions upon the manufacturer. Several instances of specifications containing some such clause as that above mentioned, and evidently copied from Mr. Deacon's paper, have lately come under the author's notice, and he therefore trusts that the foregoing experiments have conclusively demonstrated the delusive character of such a test as regards "free lime" or unsoundness. Although, of course, a user requiring an extremely slow-setting cement may, by prolonged aëration, render it so slow setting as to show practically no increase in temperature during setting, to compel a manufacturer to supply a cement complying with such a test is tantamount to asking for one containing admixtures of gypsum, or similar material, to artificially render it slow setting.

Nor does it by any means follow, that because a cement develops considerable increase of temperature during setting, that it is therefore too quick setting for proper use. To quote from the paper just previously mentioned :—†

"The mere statement that a cement shows a rise of 15°

* 'Transactions Society of Engineers,' 1903.

† 'Transactions Society of Engineers,' 1903.

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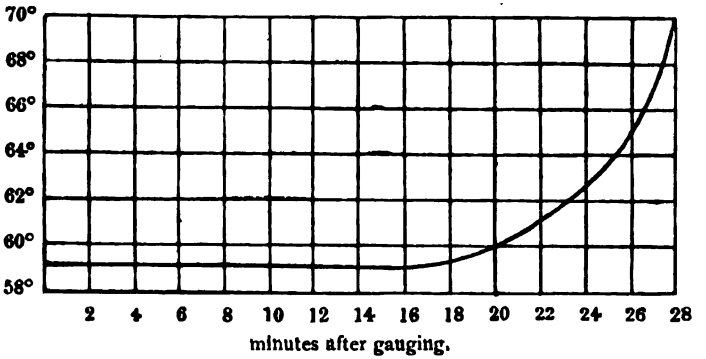
or 20° F. during setting really indicates nothing, except that at some period or other during setting, the crystallisation was very rapid. It frequently happens that a cement does not commence to set until 15 or 20 minutes, or often longer, after the addition of water, and then the crystallisation proceeds at such a rapid rate that it is set hard within 15 or 20 minutes from the time that the hardening commenced. Four examples of this kind are given in the table on page 261.

"To make the matter perfectly clear a diagram of the temperature curve of sample No. X. is given below.



"To assume, therefore, that because a cement shows a considerable rise of temperature, it is consequently too quick setting for ordinary use is altogether fallacious, because a cement which has an initial set of 10 or 15 minutes when gauged neat would have that time prolonged to at least 30 or 45 minutes when mixed with sand or aggregate, which is ample time in most classes of constructional work to allow of the concrete being got into position before setting commences. When once the concrete is in position, and at rest, it surely cannot matter how soon or how rapidly the hardening proceeds; in fact, in many cases rapid hardening is an advantage, as it allows the work to be proceeded

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EXAMPLES OF CEMENT SHOWING CONSIDERABLE RISE IN TEMPERATURE, AND YET HAVING A SUFFICIENTLY SLOW INITIAL SET FOR ALL GENERAL CONSTRUCTIVE WORK.

Sample No.	Fineness.			Setting Properties.		Increase in Temperature during Setting.	Tests for Soundness.	
	100	76	50	Initial Set.	Final Set.		Faija.	Deval.
IX.	6 p.c.	1 p.c.	Trace	20 mins.	40 mins.	Rise in temperature 1 min. after gauging = 0° " " 5 " " = 0° " " 15 " " = 0° " " 18 " " = 0° " " 20 " " = 1° " " 25 " " = 6° " " 30 " " = 11°	Sound	Sound
X.	11 p.c.	3 p.c.	0·6 p.c.	20 mins.	45 mins.	Rise in temperature 1 min. after gauging = 0° " " 5 " " = 0° " " 15 " " = 0° " " 18 " " = 0° " " 20 " " = 1° " " 25 " " = 4° " " 28 " " = 11°	Sound	Sound
XI.	12 p.c.	1·8 p.c.	0·2 p.c.	12 mins.	30 mins.	Rise in temperature 1 min. after gauging = 0° " " 5 " " = 0° " " 10 " " = 1° " " 15 " " = 8° " " 20 " " = 13°	Sound	Sound
XII.	4·2 p.c.	..	..	10 mins.	35 mins.	Rise in temperature 1 min. after gauging = 0° " " 5 " " = 0° " " 10 " " = 1° " " 15 " " = 11° " " 20 " " = 17°	Sound	Sound

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with more quickly than, for instance, if the subsequent induration were so slow as to prevent the centres being struck, or more weight being placed upon the previously completed work than it would safely bear."

The tendency among engineers of late years has been to specify more finely ground cements and at the same time slow setting ones; as has been shown in the preceding experiments, the two properties are absolutely antagonistic, and unless artificial means of retarding the setting, such as the addition of gypsum, are to be permitted, a finely ground cement generally means a quick setting one. As will be seen, on reference to the German standard rules in the Appendix, such additions of gypsum and similar materials up to 2 per cent. are allowed in that country, but the author is of opinion that the ultimate effects of such admixtures have not been sufficiently investigated to allow of their being accepted without reserve. Samples P and Q in the table on page 256 show very clearly that the addition of only 2 per cent. of gypsum renders a cement very much slower setting, and instances have occurred in which even as little as ½ per cent. was quite sufficient to render an otherwise impossibly quick-setting cement slow enough for all ordinary purposes.

In corroboration of the above opinion, the following extracts from researches by E. Candlot * show very clearly the effect of admixtures of gypsum upon the setting and tensile strain of Portland Cement:—

"*Setting.*—The retardation of set caused by the addition of gypsum to cement varies according to the quantity of gypsum employed.

"But the action of gypsum on the setting of cement is not always permanent, and it very often happens that if a cement containing an admixture of gypsum, is gauged a

* 'Ciments et Chaux Hydrauliques,' E. Candlot, 1891.

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Quantity of Gypsum added.	Set of the Neat Cement with Fresh Water.					
	1		2		3	
	Initial Set.	Set Hard.	Initial Set.	Set Hard.	Initial Set.	Set Hard.
per cent.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
0·0	0 7	0 22	0 7	0 15	0 2	0 5
0·5	0 50	2 43	0 10	0 17	0 2	0 5
1·0	2 40	4 50	3 50	5 0	1 30	2 35
1·5	2 57	5 17	3 50	5 0	3 20	5 15
2·0	3 0	5 20	4 20	6 45	4 0	7 0
3·0	3 0	6 40	3 45	7 0	5 0	7 0
4·0	3 30	7 0	5 0	7 0	5 0	7 0

long while after the gypsum has been added, it sets very quickly; this effect is produced particularly with cements which set very quickly when they have no admixture of gypsum, and which, after the gypsum has been added, have been exposed to the air for several days. [The results of some experiments on this point are shown on next page.]

"When a cement is preserved from contact with air, the set may again become quick after a lapse of a very long period.

"*Example.*—Cement mixed with 2 per cent. of gypsum and preserved in an air-tight flask.

	Initial Set.	Set Hard.
	h. m.	h. m.
Tests made the same day . .	3 0	6 25
„ 1 month after . .	2 50	5 0
„ 2 months after . .	1 30	7 0
„ 5 „ . .	0 10	0 18

"Cements containing an admixture of gypsum, present

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this peculiarity, that they often set more rapidly when gauged with sea water, than when gauged with fresh water.

Description of Cement.	Set with Fresh Water.			
	Initial Set.		Set Hard.	
	h.	m.	h.	m.
1. Cement mixed with 3 per cent. of gypsum—				
Tests made the same day . .	1	0	7	0
„ 4 days after . .	0	5	2	15
„ 7 „ . .	0	5	0	20
„ 11 „ . .	0	8	0	30
„ 15 „ . .	0	5	0	30
„ 19 „ . .	0	7	0	35
„ 24 „ . .	0	5	0	25
„ 32 „ . .	0	10	0	30
„ 41 „ . .	0	45	5	30
2. Cement mixed with 2 per cent. of gypsum—				
Tests made the same day . .	5	0	19	0
„ 12 days after . .	4	40	14	0
„ 21 „ . .	0	18	0	50
3. Cement mixed with 1 per cent. of gypsum—				
Tests made the same day . .	5	30	8	30
„ 8 days after . .	0	18	2	30
„ 15 „ . .	0	11	0	20
4. Cement mixed with 1 per cent. of gypsum—				
Tests made the same day . .	6	0	9	30
„ 8 days after . .	4	30	8	0
„ 15 „ . .	0	15	0	30
„ 30 „ . .	..		7	0

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"When a cement containing gypsum has been exposed to the air and has become quick setting again, it sets quicker when gauged to a thin consistency with an excess of water, than when it is gauged to a stiff paste with very little water. This is contrary to that which always takes place with cements not containing admixtures of gypsum.

TESTS WITH FRESH CEMENT.

Description of Mortar.	Period elapsed since gauging.	Tensile Strength in kilogrammes per square centimetre. Quantity of Gypsum added to the Cement. 0 per cent.		1 per cent.		2 per cent.		3 per cent.		4 per cent.	
		fresh water	sea water	fresh water	sea water	fresh water	sea water.	fresh water.	sea water.	fresh water	sea water.
		k.	k.	k.	k.	k.	k.	k.	k.	k.	k.
Neat cement.	7 days	34·2	39·2	45·5	53·1	37·5	43·0	30·6	31·5	18·6	25·9
	28 ,,	47·4	51·6	51·9	60·6	47·5	58·7	55·7	63·4	34·0	26·2 (1)
	3 months	51·7	54·5	55·1	50·7	59·0	65·9	62·1	69·3 (1)	65·2	25·6 (3)
	6 ,,	50·9	51·5	59·2	59·7	57·0	50·0 (1)	63·2	67·0 (3)	72·4	0 (4)
	12 ,,	60·6	25·1	59·7	48·3	63·9	31·9 (3)	65·6	72·0 (3)	80·0	0
Mortar 3 to 1.	7 days	15·7	14·9	17·7	17·0	18·5	16·2	13·0	13·4	8·9	9·9
	28 ,,	23·4	18·0	26·6	23·1	26·6	20·2	25·2	18·4	20·5	0 (4)
	3 months	30·0	21·6	34·2	25·9	32·7	24·2	33·6	23·6	31·0	0
	6 ,,	32·7	23·1	37·7	25·7	35·7	28·0	38·2	29·2	36·1	0
	12 ,,	35·5	28·2	37·7	27·5	36·0	31·9	37·7	31·0	41·5	0
Mortar 3 to 1, briquettes kept in air.	7 days	16·9	..	19·7	..	19·9	..	15·5	..	11·7	..
	28 ,,	28·6	..	35·9	..	33·7	..	29·5	..	26·9	..
	3 months	35·2	..	43·4	..	42·9	..	40·1	..	42·2	..
	6 ,,	44·2	..	45·2	..	45·6	..	50·5	..	46·9	..
	12 ,,	53·0	..	49·5	..	50·4	..	51·1	..	58·2	..

NOTE.—1 kilogramme per square centimetre = 14·228 lbs. per square inch.

(1) Briquettes showing some signs of alteration.
(3) Briquettes very much cracked and blown.
(4) Briquettes completely decomposed.

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"*Strength.*—The addition of small quantities of gypsum to Portland Cement results in increasing its strength. When however a cement is kept in sea-water and the proportion of gypsum added exceeds 1 to 2 per cent. the mortar is not long before it shows traces of alteration, and the briquettes are sometimes completely disintegrated. (See table on p. 265.)

TESTS MADE WITH THE SAME CEMENT KEPT IN SACKS FOR TWO MONTHS.

Description of Mortar.	Period elapsed since gauging.	Tensile Strength in kilogrammes per square centimetre. Quantity of Gypsum added to the Cement. 0 per cent. fresh water	0 per cent. sea water	1 per cent. fresh water	1 per cent. sea water	2 per cent. fresh water	2 per cent. sea water	3 per cent. fresh water	3 per cent. sea water.	4 per cent. fresh water	4 per cent. sea water.
		k.	k.	k.	k.	k.	k.	k.	k.	k.	k.
Neat cement.	7 days	28·0	35·6	28·5	34·1	21·0	25·2	15·0	13·4	11·6	12·6
	28 ,,	47·0	48·5	42·9	48·2	37·5	48·9	34·2	40·9	22·9	16·5 (2)
	3 months	52·2	63·1	51·7	56·1	53·3	50·9	48·7	48·1 (1)	50·9	37·7 (3)
	6 ,,	55·2	49·2	54·9	55·5	49·2	52·0	51·2	52·0 (2)	58·6	43·4 (3)
	12 ,,	59·7	17·6	56·0	27·7	53·0	50·5	58·5	51·6 (2)	54·7	46·0 (3)
Mortar 3 to 1.	7 days	14·1	15·2	15·2	13·6	15·7	13·0	6·6	7·0	5·1	5·6
	28 ,,	23·7	22·1	22·0	22·2	21·5	18·0	21·6	18·0	17·2	12·1
	3 months	29·7	27·0	29·2	26·2	28·2	20·9	33·7	25·0	28·5	19·5
	6 ,,	31·9	27·5	31·9	24·4	34·2	24·7	35·7	25·6	37·3	22·4
	12 ,,	35·6	29·4	36·1	27·5	34·4	26·5	38·0	25·6	36·5	26·2
Mortar 3 to 1, briquettes kept in air.	7 days	13·7	..	19·1	..	15·7	..	6·2	..	5·1	..
	28 ,,	28·6	..	31·0	..	28·6	..	26·9	..	23·7	..
	3 months	37·6	..	41·1	..	35·6	..	36·6	..	33·7	..
	6 ,,	47·2	..	49·9	..	43·7	..	47·5	..	43·0	..
	12 ,,	56·7	..	59·9	..	51·1	..	57·7	..	56·7	..

NOTE.—1 kilogramme per square centimetre = 14·228 lbs. per square inch.

(1) Briquettes showing some signs of alteration.
(2) Briquettes cracked.
(3) Briquettes very much cracked and blown.

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" If the cement containing gypsum is allowed to remain in sacks for several weeks, it develops very poor strains at the early dates of testing." (See table on p. 266.)

As the result of a considerable series of chemical researches in the matter, M. Candlot comes to the conclusion that the peculiar effects of adding gypsum to Portland Cement are due to the formation of a sulpho-aluminate of lime, a salt which he succeeded in producing artificially, and to which he attributes the formula (Al_2O_3, 3CaO) 2·5 (SO_3,CaO). From this he deduces the following theory :—

" It is well known that aluminate of lime is insoluble in a saturated solution of lime. If, then, sulphate of lime and free lime are present together with aluminate of lime, it follows that the combination of the sulphate of lime with the aluminate can take place but very slowly, because the aluminate cannot become hydrated on account of the immediate solution of the lime. Thus, a mixture of powdered aluminate of lime, of sulphate of lime and of slaked lime, having been shaken with an excess of distilled water, produced the following results :—

Periods after which samples of the liquid were taken.	Matters in solution per litre of liquid in grammes.		
	CaO.	Al_2O_3.	SO_3.CaO.
	gr.		gr.
10 minutes	1·085	nil	1·734
3 hours	1·085	..	1·632
6 „	0·875	..	1·632
12 „	0·930	..	1·504
8 days	1·085	..	nil
1 month	0·304	..	..

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"The above shows that the combination of the sulphate with the aluminate only takes place after a considerable period, the aluminate becoming hydrated but very slowly.

"In Portland Cements of the best manufacture, there always exists a little free lime; and, as they contain very little alumina, this free lime, by rapidly dissolving, prevents the hydration of the aluminate; the sulphate of lime becoming dissolved in turn, and not being able to combine with the aluminate, adds its action to that of the lime in annulling the function of the aluminate; as it is to this salt that setting is attributable when it takes place rapidly, a slow-setting cement results.

"If the free lime, by being sufficiently exposed to the air, becomes carbonated, at the moment when the cement comes into contact with the water, the lime dissolves less freely, and nothing prevents the solution of the aluminate; the combination with the sulphate of lime can take place, and the sulpho-aluminate formed, as well as the excess of aluminate, by crystallising, determine the rapid setting of the cement."

Candlot then gives the following experiment to show that the above is probably what takes place.

1. A fresh cement to which gypsum has been added, and setting slowly with fresh water, sets quickly if gauged with a solution containing a sufficient quantity of carbonate of soda to neutralise the free lime, for example:—

	Set. h.	m.
a. Cement with 1 per cent. of gypsum added, gauged with pure water . . .	8	0
b. Same cement, gauged with a solution of carbonate of soda containing 2 grammes per litre.	0	30

2 A cement with gypsum added is left exposed to the air, and at the end of several days it becomes quick setting; if now a small quantity of slaked lime is added to the cement, it is rendered very slow setting.

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	Initial Set.		Set Hard.	
	h.	m.	h.	m.
a. Cement containing 2 per cent. of gypsum	0	20	2	30
Same cement, to which 2 per cent. of lime has been added . .	6	0	10	0
b. Cement containing 1 per cent. of gypsum	0	10	0	20
Same cement, to which 2 per cent. of lime has been added . .	1	0	8	0

The foregoing results show conclusively that additions of gypsum are not always an unmixed advantage, and, as before stated, the exact effect of such admixtures require to be more fully understood and realised before they can be lightly accepted. Of course, from the manufacturer's point of view, admixtures of gypsum or some material having the effect of retarding the setting of cement would be an inestimable boon to those who are bound by the clauses of a specification to supply a slow setting and finely ground cement. Such admixtures would be more especially appreciated during the summer months and in tropical climates, where the natural quick-setting properties of a cement are materially aggravated by climatic conditions of temperature, etc. Where such small additions of material like gypsum are found to produce such marked results, another difficulty that must not be overlooked is the danger arising from imperfect incorporation of the admixture with the whole of the cement. It is usual to add the gypsum to the clinker at the crushers, in the course of manufacture, and it will be readily understood that the regular and uniform addition of such small quantities as ½ and 1 per cent. is no easy matter; in fact, that was the reason recently put forward by one large firm of manufacturers for not employing such additions unless they were absolutely obliged.

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CHAPTER VI.

WEIGHT, SPECIFIC GRAVITY, AND COLOUR.

THE object of ascertaining the weight per bushel of a cement is to enable some opinion to be formed of the amount of calcination to which the sample has been subjected, as, *cæteris paribus*, the harder it is burned the greater will be the weight per bushel.

The weight per bushel test is really a relic of olden days, when cement was sold by the bushel, and is of no value whatever to the user as to the quality of a cement, inasmuch as it is chiefly governed by the fineness to which the sample is ground, and its age. On these points the following experiments by Faija are interesting and conclusive :—*

——	No. 1.	No 2.
	lbs.	lbs.
Weight when received	113	112
„ in one month	110	111
„ in three months . . .	102	102
„ in six months	100	99
„ in nine months . . .	97	..
„ in one year	95	..
Loss in six months . . per cent.	11·5	11·6
„ in twelve months . . „	15·9	..

* 'Transactions Society of Engineers,' 1888.

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It will be seen that a cement a year old weighs about 18 lbs. less per bushel than when fresh, or loses about 15·9 per cent., while at six months the loss is about 11·55 per cent. Then, again, the finer a cement is ground the less it weighs per striked bushel, so that to ask for a heavy cement is tantamount to asking for a coarsely ground one. Though this is pretty generally known now, the following experiments made by the same authority several years ago may be of interest:—

—	Residue on No. 50 × 50 Sieve.	Weight per Bushel.
	per cent.	lbs.
No. 1 cement	6	109½
The same cement ground to all pass a 100 × 100 sieve	Nil.	100¼
No. 2 cement	25	114
The same cement ground to all pass a 50 × 50 sieve	Nil.	104
No. 3 cement	16	116
The same cement ground to all pass a 50 × 50 sieve	Nil.	109
No. 4 cement	14	116½
The same cement ground to all pass a 50 × 50 sieve	Nil.	112
No. 5 cement	33	118½
The same cement ground to all pass a 50 × 50 sieve	Nil.	105

To the manufacturer the weight per bushel is of some considerable value, as the author has found in practice; every manufacturer knows what his cement should weigh if properly calcined and ground to a certain degree of fineness, and, by periodically taking the weight per bushel through-

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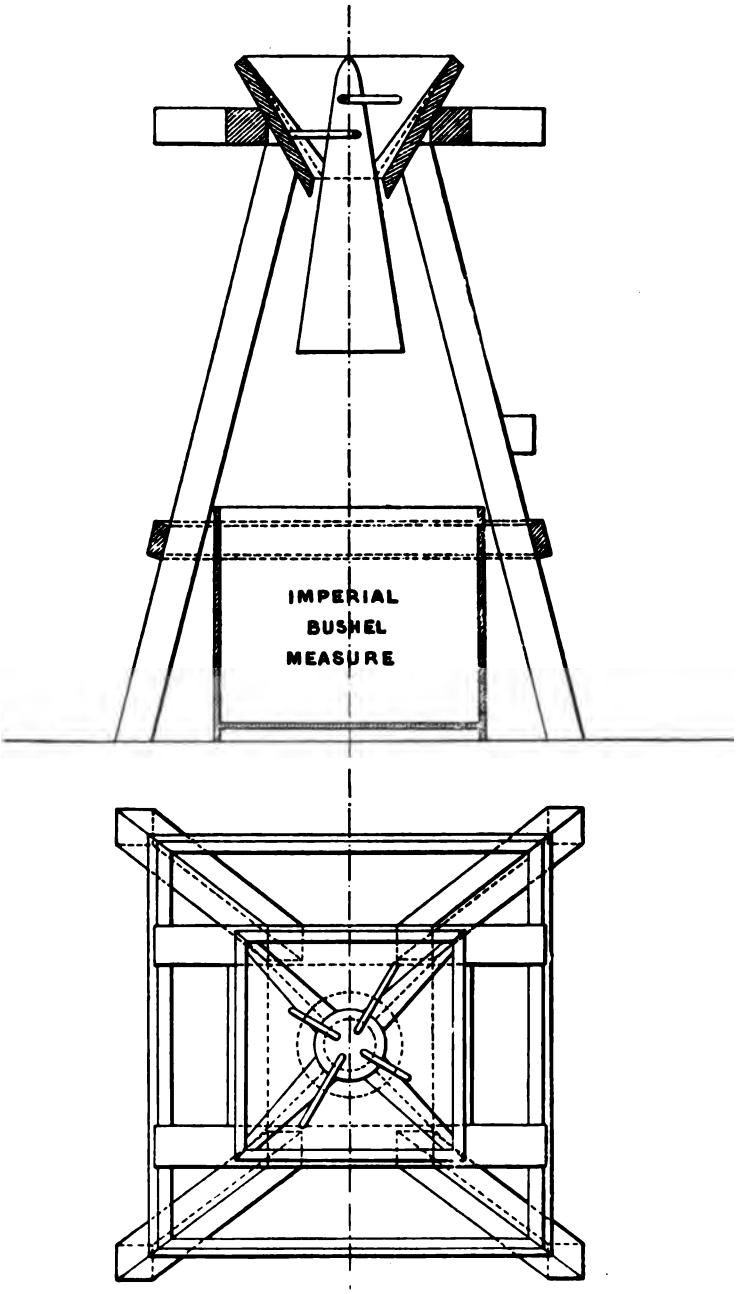

FIG. 77.

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out the day, he is able to keep a check upon the amount of calcination it has received.

In ascertaining the weight per bushel the measure should be filled as lightly as possible, and the contents struck off level at the top. The best known apparatus for this purpose is that adopted by the late Sir John Coode, a sketch of which is given in Fig. 77. It consists of a hopper carried on a convenient frame, into the apex of which is fitted an elongated cone. This cone is supported by and pivoted on four horizontal pins or bars resting on the internal surface of the hopper, as shown ; the space between the cone and the hopper is ½ inch wide, so that the cement has only a very narrow outlet through which to pass from the hopper, and must therefore flow in a very steady stream. The top of the bushel measure is 1 foot 6 inches from the mouth of the hopper, and the cone projects 9 inches below this mouth ; the cement is fed into the hopper with a shovel, and therefore slides down the cone for 9 inches, and then drops direct into the measure.

The object of every apparatus used for determining the weight per bushel is that the cement shall fall into the measure in a steady uniform stream from a given height, it being very evident that if it is roughly shovelled in, the weight will be considerably greater than when lightly filled. Fig. 78 is a sectional illustration of the hopper devised and used by the late Henry Faija. It consists of an ordinary hopper, A, carried in a suitable framing, and of sufficient capacity to hold rather more than a bushel of the material to be weighed. At its apex is a horizontal conveyor trough, into which the cement falls, and by turning the handle D, which actuates the conveyor, it is brought forward to the opening E, whence it falls into the measure in a steady uniform stream. When the measure is piled full, the hole E is closed by the handle F, which works a sliding shutter.

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The cement can then be struck off level at the top with a straight-edge in the usual way. For use on works the lower part is made open as shown. For testing-room use, where the dust arising from the filling and striking off of the measure would be a source of considerable annoyance, the lower

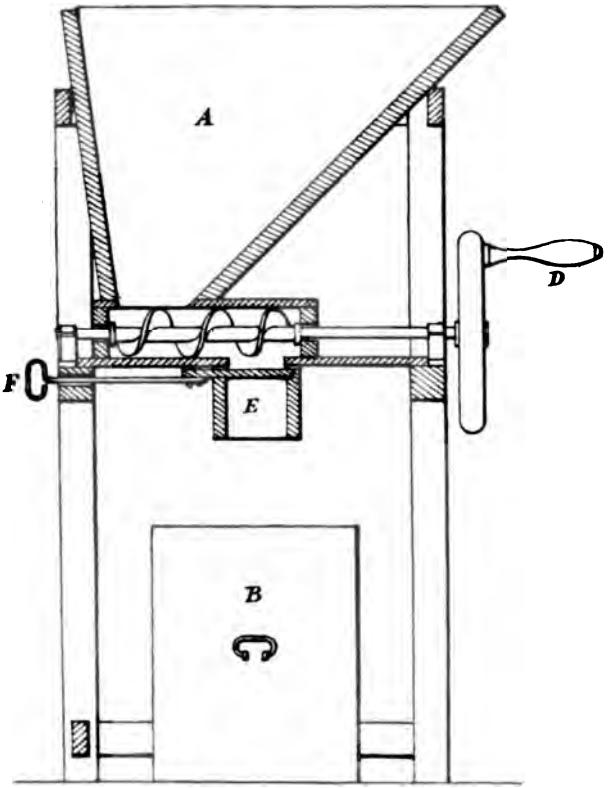

FIG. 78.

part of the framing is boarded up and enclosed, so that the whole of the dust is confined within it. A movable door is arranged at the front, to allow of the passage of the bushel measure, which is run in and out on a deep tray fitted with castors to facilitate removal. This tray covers the whole of

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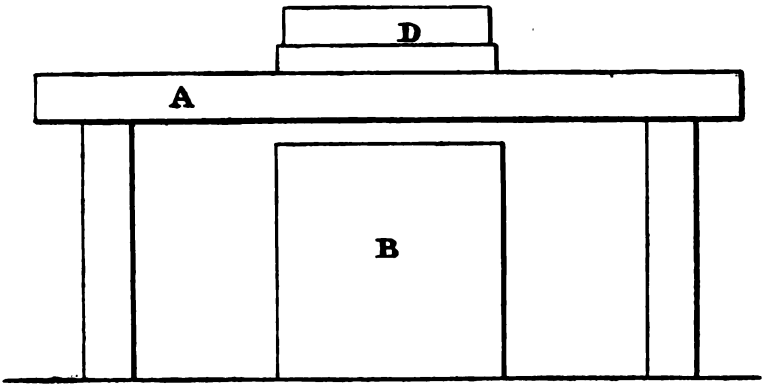
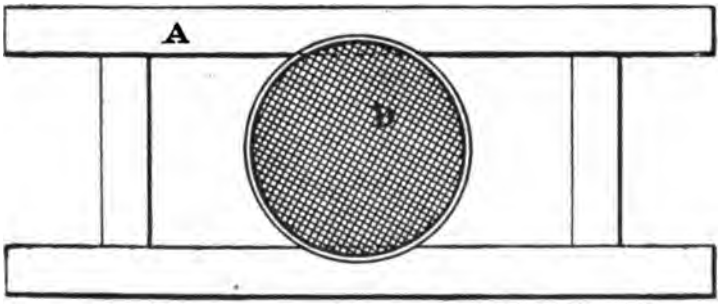
the floor space of the apparatus, and consequently catches all the superfluous cement in striking off. Glass shutters are arranged at each side, at about the level of the top of



ELEVATION.



PLAN.

FIG. 79.

the bushel, so that when the measure is seen to be full the straight-edge can be passed through over the top and the contents struck off level.

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A very simple arrangement for filling the bushel measure, where neither of the foregoing apparatus is available, is that shown in Fig. 79. It consists of an ordinary sieve, D, of any convenient diameter, and having about ten holes per lineal inch, which is worked to and fro on the top of a stool-shaped frame, A; the cement is fed into the sieve by means of a small shovel, and passes through it in a constant stream into the measure B below. This arrangement gives results which compare very well with more elaborate devices. It is unnecessary to add that with this and all arrangements for estimating the weight per bushel, the measure must not be touched or jarred before being struck off level, and the operation must be conducted on a solid floor free from vibration of any kind.

The specific gravity, i.e. the weight of a substance compared with water, is a more reliable criterion of the relative weight of cement, as it is not affected by the fineness of grinding; the age of the sample, however, largely affects its specific gravity, though not to such a degree as its weight per bushel. The following experiments, taken from the paper previously quoted,* show very clearly the effect of age upon the specific gravity of cement.

—	No. 1.	No. 2.	No. 3.	No. 4.
Specific gravity when received .	3·16	3·175	3·16	3·12
„ in one month .	3·055	3·125	3·13	3·109
„ in three months .	3·095	2·965	3·084	2·985
„ in six months .	3·016	2·93	3·018	2·995
„ in nine months .	2·969	2·915	3·015	2·985
Loss in six months (per cent.) .	4·55	7·71	4·49	4·006

* 'Transactions Society of Engineers,' 1888.

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Cement being a hydraulic material, i.e. setting under water, it is impossible to estimate its specific gravity by weighing in water in the ordinary way, and it is therefore necessary to use a liquid which does not put in motion its setting properties. The most convenient and generally used liquids for this purpose are ordinary paraffin and turpentine.

The method used by some operators of ascertaining the specific gravity of cement is to simply estimate the weight of paraffin of known specific gravity displaced by 100 grains of cement, and calculate the specific gravity of the latter therefrom. For this purpose an ordinary specific gravity bottle with a perforated stopper is used, the weight of which is counterpoised on the balance. It is then filled with paraffin and weighed. The stopper being perforated enables it to be filled without any of the liquid escaping down the side, any slight excess being readily intercepted through the stopper. The weight of the paraffin being recorded, the greater part of it is emptied out and the 100 grains of cement introduced into the bottle by means of a small funnel. The stopper is then replaced, and the bottle and the contents are gently shaken to get rid of any air-bubbles. The bottle is then again filled with paraffin and weighed : its weight, minus the 100 grains of cement, gives the actual weight of paraffin present, and the difference between that figure and the weight of the bottle filled with paraffin only, gives the weight of the paraffin displaced by the 100 grains, or, in other words, the relative weights of similar bulks of paraffin and cement. The weight of the substance taken, divided by the weight of paraffin displaced, gives the specific gravity of the cement compared with paraffin ; this result, multiplied by the specific gravity of the paraffin, gives the specific gravity of the cement. The specific gravity of the paraffin is, of course, easily ascer-

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tained by means of an ordinary hydrometer, and the only calculation necessary is—

$$\frac{\text{Weight of cement taken} \times \text{S.G. of paraffin}}{\text{Weight of paraffin displaced}} = \text{S.G. of cement.}$$

As the weight of cement taken was 100 grains, it merely means dividing the specific gravity of the paraffin by the weight of paraffin displaced, and moving the decimal point two places to the right.

A very convenient apparatus for determining specific gravity is that devised by Mr. Mann, an illustration of which is given in Fig. 80. Mr. Mann describes his apparatus as follows:— *

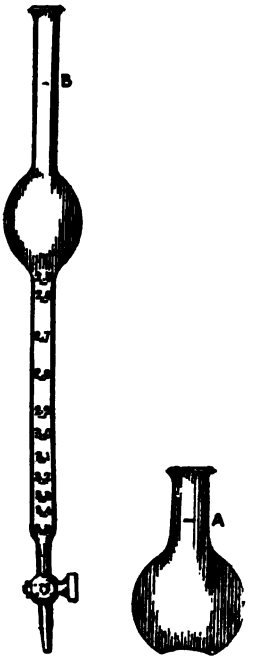

FIG. 80.

"It consists of a small glass vessel, holding, when filled to a mark A on the neck, a given quantity of liquid, and of a glass pipette furnished with a graduated stem and stop-cock, and containing, when filled to a mark B on its upper extremity, a volume of liquid equal to that held by the first mentioned vessel, *minus* the quantity displaced by 1000 grains of the densest substance intended to be examined.

"In using the gravimeter the pipette is filled to the mark B with paraffin, turpentine, spirits of wine, or any other liquid which does not act on the cement (preferably paraffin); 1000 grains of the cement are then introduced

* 'Proceedings Institution Civil Engineers,' vol. xlvii. pp. 251 and 252.

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into the smaller vessel, which is placed under the pipette and filled to the mark A. Before this is quite completed, the vessel may be corked, and the contents shaken to remove any small air-bubbles that may be entangled in the cement. The height of the column of liquid remaining in the pipette determines the specific gravity which can be at once read off on the graduated stem. It is manifest that the denser the substance operated upon, the less liquid will be displaced in the smaller vessel, and therefore the less will remain in the pipette, and *vice versâ*. In reading the accompanying gravimeter, the second place of decimals is estimated. Any greater degree of delicacy may be obtained either by diminishing the diameter of the stem or by reducing the range.

"The specific gravity of any solid substance coming within the range of the instrument can, of course, be taken in the same manner. The advantages claimed for this gravimeter are, that neither the density nor the temperature of the liquid used need be taken into account; one weighing is sufficient, and all arithmetical calculations are dispensed with; it is also inexpensive, and requires little skill in manipulation.

"In order to test the accuracy of the instrument, a small piece of granite was reduced to powder and its specific gravity taken by the gravimeter; the specific gravity of an unpulverised piece was then ascertained by the ordinary method. Similar experiments were also made with a piece of limestone. The results were:—

Granite	Specific gravity by gravimeter	2·62
	„ „ ordinary method	2·63
Limestone	Specific gravity by gravimeter	2·70
	„ „ ordinary method	2·71

This apparatus is still considerably used in England, and it certainly has the advantage of simplicity, only one

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weighing (that of the 1000 grains of cement) being necessary, and no calculation being required. The author's experience of it is, that it is very difficult to get rid of all the air bubbles; the method of corking and shaking suggested by Mr. Mann would unavoidably lead to loss of liquid, and consequently an erroneous result. Another source of error is that the bulk of the liquid is sensibly affected by the slightest change in temperature, to say nothing of the probable loss by evaporation. Although not scientifically accurate, this apparatus is perhaps sufficiently so for general work, especially if the mean be taken of several experiments.

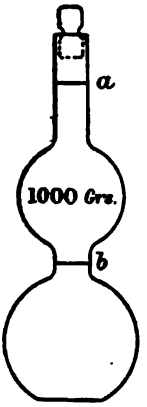

FIG. 81.

Fig. 81 shows Keate's double bulb specific gravity flask. As will be seen from the illustration, it consists of two bulbs, one above the other, the neck of each bulb being marked. The bottom bulb is of any given capacity, but the capacity of the upper bulb between the two marks is that of 1000 grains of water at normal temperature. To ascertain the specific gravity by this apparatus the lower bulb is filled with paraffin up to the mark on the neck, and the weight of the whole taken. The cement is then introduced into the flask until the liquid rises to the mark on the neck of the upper bulb. The whole being again weighed, the increase in weight gives the weight of a bulk of cement equivalent to a bulk of 1000 grains of water. The specific gravity of the substance is, of course, the increase in weight divided by 1000.

There are several forms of specific gravity apparatus in use on the Continent, of which the most popular is, perhaps, that of Schumann, shown in Fig. 82. It consists of a

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graduated tube A, ground, stopper fashion, into the neck of a small flask. This tube is graduated into tenths of a cubic centimetre, the graduated portion ranging from zero to 40 c.c. To estimate the specific gravity by this apparatus, the stoppered tube is tightly fixed into the neck of the flask, and paraffin introduced until both flask and tube are filled up to the zero mark or one of the first graduations on the scale. The exact reading being taken, 100 grammes of cement are thereupon gradually introduced down the tube, and the reading again taken. The difference between the readings gives the displacement of the paraffin, which indicates the bulk occupied by the 100 grammes of cement As the space occupied by the paraffin is considerably affected by the least variation in temperature, it is essential that its temperature should be the same at each reading, and for that purpose the bulb of the apparatus is placed under water of constant temperature a short time before the height of the liquid is read off.

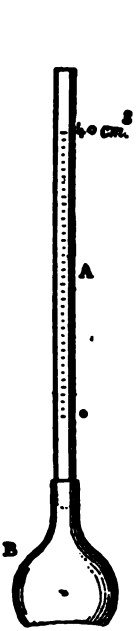

FIG. 82.

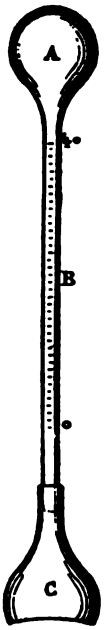

FIG. 83.

Fig. 83 shows a modification of the Schumann apparatus devised by M. Candlot. It is exactly the same in every respect, except that the top of the tube terminates in a bulb. A sufficient quantity of paraffin is introduced into the bulb, so that when the flask is attached, and the apparatus reversed, the flask is filled as far as one of the first

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graduations of the scale. Again reverse the apparatus so that the paraffin flows back into the bulb, and then introduce 100 grammes of cement into the flask. On again carefully tilting the apparatus, the paraffin flows back into the flask, and the displacement caused by the cement is shown on the graduated tube. As with the Schumann apparatus, the accuracy of this volumeter depends to a considerable extent upon the temperature of the paraffin being the same at each reading, and the temperature should therefore be equalised before the height of the liquid is read off, by immersing it for a short time in water.

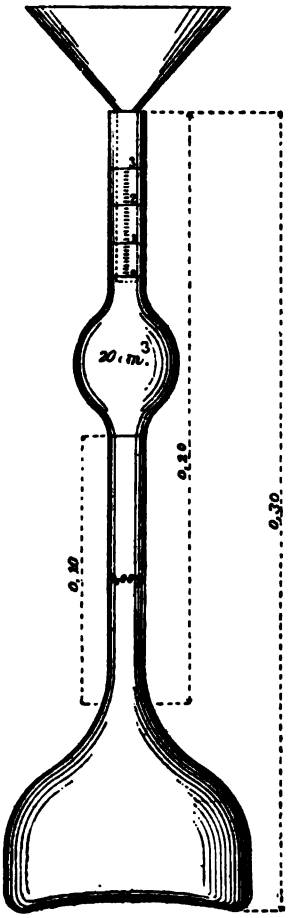

FIG. 84.

Fig. 84 shows the apparatus designed by M. H. Le Chatelier, which is recommended by the French Commission des Méthodes d'Essai des Matériaux de Construction. As will be seen from the illustration, it consists of a flask of about 120 c.c. capacity, having a neck about 20 cm. long and about 9 mm. in diameter. About half-way up the neck is a bulb of exactly 20 c.c. capacity, indicated by marks above and below it. Commencing at the mark above the bulb, the tube is graduated from zero to 3 c.c. in tenths of a centimetre. The method of using the

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apparatus is as follows. Fill the flask with paraffin up to the mark below the 20 c.c. bulb, weigh out exactly 64 grammes of cement and introduce it into the neck of the flask by means of a funnel. The bottom of the funnel should reach just below the first graduations, so that should the powder fall against the side of the neck, it will be below the space eventually occupied by the paraffin, and will not affect the accuracy of the results. The cement is added until the paraffin rises to the zero mark on the neck above the 20 c.c. bulb. The remainder is then weighed, and the quantity that has been introduced into the bottle corresponds with the weight of cement equivalent to 20 c.c. of water. An alternative arrangement is to introduce the whole of the 64 grammes, and by reading off on the graduated scale the additional space occupied over and above 20 c.c., the bulk of the liquid displaced is estimated ; then, as before, the weight of cement taken divided by the weight of water (or its equivalent in bulk) displaced, gives the specific gravity of the substance. To equalise the temperature of the liquid, the bulb should be immersed in water a short time before each reading.

With every apparatus for determining the specific gravity of cement, the difficulty is to get rid of the air bubbles entangled between the particles, or, as with the Schumann type of apparatus, carried down by them on their passage through the liquid ; and unless these air bubbles are entirely expelled by gently tapping or shaking, or other means, the result will be proportionately erroneous. When using volatile liquids, the loss caused by evaporation may be considerable, especially in warm weather, and therefore the temperature should be kept as nearly normal as possible.

The specific gravity of a well-burned cement should not be less than 3·1, and a great many cements will show

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as high a specific gravity as 3·15, or even higher when freshly burned. The value of the specific gravity as a test of quality is rather problematical, for although a high specific gravity is usually taken to indicate a well-burned cement (a conclusion which a series of researches now in hand causes the author to doubt very much), the amount of burning which a cement requires depends largely upon its chemical composition, and the care with which the raw materials have been blended in the first operation of mechanical mixture. It very often happens that a sample with a comparatively low specific gravity has a much greater value, as a constructive material, than one with a high specific gravity; it is therefore a test which must be carefully considered in conjunction with the other characteristics developed by the sample under examination.

The chief advantage of the specific gravity is that it is only affected by the age of the sample, whereas with the weight per bushel, the age, fineness, and even the apparatus used, affect the result obtained, in fact the latter is by no means the least important factor. The reason why the age of a sample affects its specific gravity is that it absorbs moisture and carbonic acid from the air, the quantity depending of course upon the amount of exposure and on facilities for absorption. As the specific gravity of these matters is considerably less than that of cement, it will be readily understood that any considerable absorption will materially affect the result. This, however, can be practically obviated, where such facilities exist, by heating the cement to redness, and allowing it to cool in a desiccator before taking its specific gravity; by this means it is reduced to practically the same condition as when it left the mill.

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Colour.

The colour of a cement is very often of considerable value to the experienced operator in roughly estimating its probable qualities. This remark is more especially true from a manufacturer's point of view, as, knowing the colour which his product should be if properly proportioned and calcined, he can generally detect any serious fault, either in proportion or calcination, from the appearance of the cement, either when in a state of powder or gauged into a briquette or pat. It is, therefore, a very general custom to leave one pat from each set of the briquettes exposed to the air for a few days, in order to determine the colour of the sample. The colour of a well-proportioned and well-calcined cement should be of a cold blue-grey when in the powdered condition; if of a brownish colour, or, as it is technically called, "foxy," it denotes either insufficient calcination, or the use of an unsuitable clay, or possibly excess of clay. A cement that contains an excess of clay is, as a rule, extremely quick setting, and never attains any very great strength. Generally speaking, a dark, bluish-grey colour denotes a thoroughly burned cement, and one that contains a sufficiency of lime. For constructive purposes the colour of a cement is a secondary consideration, unless used for stucco and similar work where it is exposed to view. In that case the colour is of some considerable importance, as nothing looks more disagreeable than a piece of cement plastering, such as the wall of a building, which instead of being of a dark, cold blue-grey colour, is a dirty "foxy" brown. This "foxy" colour is sometimes brought about by excessive trowelling, especially when a cement is quick setting, and, as sometimes happens, is worked for a moment or two after setting has actually commenced. The effect of over-trowelling on

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the colour of a cement was lately very clearly illustrated in the author's testing room. Of a series of samples which were taken from the same bulk, the trial pats of two were gauged immediately on receipt, and the remainder, owing to unavoidable circumstances, had to be left till a few days later; during this time they became quicker setting, so quick setting indeed that they could with difficulty be gauged. The pats of each were left in air, and those which afforded plenty of time to the operator were of a very good colour, while those which were barely finished before setting had commenced, were of a very disagreeable brown "foxy" colour on the surface. The same thing may often be noticed with briquettes made from a very quick setting cement, the trowelled surface which is exposed to the air frequently developing the brown colour previously mentioned. Another matter of manipulation which often affects the colour of a sample, is the amount of water used for gauging; with a slow setting cement the less water used, the darker and better will be the colour of the surface of the briquettes where exposed to the air. It is usual to cover the briquettes after gauging, with a damp cloth or a damp cloth lined box during the twenty-four hours in which they are left in air, which, in addition to preventing the undue evaporation of the water used for gauging, will be found to greatly preserve and improve their colour. Should the cement contain any appreciable quantity of underburned particles, they will have a tendency to rise to the surface with the water during the shaking and trowelling of the briquettes, owing to their lighter gravity; a film of a yellowish-brown colour is thus formed on the surface, which is very plainly distinguishable in the section of the briquette after fracture.

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CHAPTER VII.

CHEMICAL COMPOSITION.

TAKEN in conjunction with a mechanical examination and physical tests, a knowledge of the chemical composition of a cement is of great importance in determining its constructive value. Its chief value is in estimating the amount of active ingredients present, and also in detecting any excess of deleterious constituents. It is, however, of very little use by itself in the determination of the value of a sample, for although the cement may contain the correct ingredients, yet, owing to faulty incorporation of the raw materials, imperfect burning, or insufficient grinding, it may possess any but the properties of a good Portland Cement, these being points upon which an analysis throws little or no light. Although it may be possible occasionally to form a definite opinion as to the probable qualities of a sample from its chemical composition, owing to excess or insuffiency of certain constituents, such opinion should always be confirmed by careful physical tests.

Lime, combined as silicates and aluminates, is the chief active ingredient of cement, and it has been found in practice that, within certain limits, the more lime a cement contains the greater is its strength, although, if more lime is present than can combine chemically with the other ingredients, the cement after setting will subsequently blow and disintegrate. Apart from the chemical composition of the raw materials and the percentage of lime necessary to

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form the definite silicates and aluminates contained in a true Portland Cement, the amount of lime which a cement will safely bear depends largely upon the care and attention which has been expended upon the several processes of manufacture. A thoroughly washed, well burned and finely ground cement will bear with safety a considerably higher percentage of lime than one made from the same raw materials which have been badly incorporated, imperfectly calcined and coarsely ground. In the first instance, the mechanical mixture being imperfect, the subsequent chemical combination by calcination is also imperfect, owing to the particles of chalk or carbonate of lime being insufficiently reduced to completely combine with the silica and alumina, thus resulting in free or loosely combined lime. In the second case, insufficient heat has been applied to cause the proper chemical combination of the lime with the silica and alumina; and, by coarse grinding of the calcined material, any small particles of uncombined lime, which in a finely ground cement would be exposed to the immediate action of the water during gauging, and thus rendered innocuous, are confined within the coarse particles, and their subsequent hydration and expansion cause the disintegration of the mass.

As a case in point, the following analyses may be quoted as showing the composition of two cements of practically similar constituents, made at the same works from the same raw materials, and yet differing materially in physical properties, owing to faulty manufacture of one. Sample A, which was badly washed, i.e. the raw materials imperfectly incorporated—although it contained only 1 per cent. more lime than sample B, was burned to the same degree of hardness, and ground to the same fineness—proved to be utterly unsound; while, on the other hand, sample B, which was properly washed, i.e. the raw materials thoroughly

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amalgamated in the first process of mechanical mixture, gave perfectly satisfactory results.

	A.	B.
Silica	24·5	23·6
Alumina	8·8	9·1
Lime	62·2	61·1

According to Le Chatelier * the minimum proportion of lime in a true Portland Cement should not be less than—

$$\frac{CaOMgO}{SiO_2Al_2O_3} = 3,$$

nor the maximum greater than—

$$\frac{CaOMgO}{SiO_2Al_2O_3Fe_2O_3} = 3.$$

In putting forward these formulæ Le Chatelier assumes that not more than three equivalents of lime or magnesia can enter into combination with silica and alumina.

A very interesting series of researches as to the constitution of cement has recently been carried out by Messrs. Newberry,† of New York. By synthesis they determined that—

1st. Lime may be combined with silica in the proportion of 3 molecules to 1 ($3CaOSiO_2$), and still give a product of practically constant volume and good hardening properties, though hardening very slowly. With $3\frac{1}{2}$ molecules of lime to 1 of silica ($3\frac{1}{2}CaOSiO_2$) the product is not sound, and cracks in water.

2nd. Lime may be combined with alumina in the proportion of 2 molecules to 1 ($2CaOAl_2O_3$), giving a product which sets quickly but shows constant volume and good hardening properties. With $2\frac{1}{2}$ molecules of lime to 1 of alumina ($2\frac{1}{2}CaOAl_2O_3$) the product is not sound.

* 'Annales des Mines,' 1887, p. 345.

† 'Society of Chemical Industry,' Nov. 1897, p. 889.

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The formula $3CaO,SiO_2$ corresponds to 2·8 parts lime (CaO) to one part silica (SiO_2), and the formula $2CaOAl_2O_3$ corresponds to 1·1 by weight of lime (CaO) to 1 of alumina (Al_2O_3), and therefore the following formula is given as representing the maximum of lime in an ideal Portland Cement :—

$$\%\,CaO = \%\,SiO_2 \times 2{\cdot}8 + \%\,Al_2O_3 \times 1{\cdot}1.$$

By a series of synthetical experiments with mixtures containing various percentages of alumina, they show that cement prepared according to the above formula gives satisfactory results, whereas cement containing three molecular proportions of lime to 1 of alumina, according to the maximum laid down by Le Chatelier's formulæ, is unsound, thus showing that the lime limit has been exceeded. It is perhaps needless to reiterate that the proportions above mentioned refer only to an ideal cement, the raw components of which have been most intimately commingled and thoroughly and evenly burned, and would scarcely answer with the comparatively crude methods of treating the raw materials in the ordinary course of manufacture.

Silica in the form of silicate of lime is generally considered to be responsible for the hardening properties of a Portland Cement, apart from its setting properties, and some writers go so far as to assert that as soon as the cement is set, the function of the aluminate of lime ceases. This, however, has by no means been proved, and some natural cements are made in France which consist almost entirely of aluminate of lime. It is well known in actual practice that the hardening of cement and hydraulic limes is greatly accelerated and increased if they are subjected to a bath of silicate of soda ; and the application of this silicate bath in some form or other is the basis of the principal claim

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in more than one patent for indurating paving slabs and other moulded materials composed of Portland Cement.

Aluminate of lime is generally considered to be responsible for the setting properties of a cement, as distinct from its subsequent hardening; this view is corroborated by general experience, for as a rule the greater the quantity of alumina present, the quicker setting the cement. Assuming Le Chatelier's theory of supersaturation to be correct, it is very evident that as the aluminate of lime is the more soluble ingredient, the greater the amount of aluminate present the more readily will supersaturation occur, and therefore the more rapid will be the formation of crystals and the consequent setting of the sample.

The action of oxide of iron in cement is a little obscure, though if it is present in excess the colour of the cement is more or less affected, owing to the oxide imparting some of its colour to the cement. Cement prepared synthetically by Messrs. Newberry,* from silica, alumina and lime only, was perfectly white, whereas when iron oxide was substituted for alumina, the resulting cement was a dark grey. According to Le Chatelier, mixtures of iron oxide and lime yield, on burning, products which slake with water but possess no hydraulic properties. Messrs. Newberry state that iron oxide combines with lime in the same manner as alumina, but the amount present in ordinary clays is so small, and the quantity of lime with which it will combine so insignificant, that its effect is extremely difficult to trace. The author's experience is that a moderate percentage of iron does not materially affect the constructive value of the cement, and that its chemical action is somewhat similar to that of alumina.

Sulphuric anhydride in excess, say more than 3 per cent., is frequently a source of danger, and a case oc-

* 'Society of Chemical Industry,' Nov. 1897, p. 889.

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curred a year or two ago where that constituent caused serious trouble to the manufacturer. It was found that the cement occasionally had a tendency to "blow," sometimes in a very marked degree, and as the percentage of carbonate of lime in the slurry was the same in each case, it was a little perplexing to discover the cause. On the defective samples being analysed it was found they contained a considerable excess of sulphuric anhydride; an examination was therefore made of the raw materials from which the cement was made, and it was found that the clay, which was of a blue Gault formation, contained a considerable quantity of nodules of gypsum or natural sulphate of lime, the quantity varying in different parts of the pit. A certain proportion of the sulphates emanates from the coke used in calcination, as raw materials which contain no appreciable quantity of sulphate of lime are sometimes found to produce a cement containing between 1 and 2 per cent. of that constituent, the presence of which can only be attributed to the sulphur in the coke. The analysis of various coke ashes given on page 73 bears out this view. The presence of sulphur as sulphides is generally the chief difficulty to be contended with in making cement from alkali lime waste, and up to the present time cements made from that material have not met with much success, owing to the difficulty in sufficiently cleansing the waste of that objectionable constituent. The chief danger arising from an excess of sulphide is that its subsequent oxidation and conversion into sulphate would probably cause expansion and disintegration.

Magnesia is an ingredient about which there was a considerable scare a few years ago, when the failure occurred at the Aberdeen Harbour Works. The disintegrated cement and the white deposit found in the work that failed were analysed, and the latter was found to consist largely

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of magnesia; the inference drawn therefrom was that the magnesia in the cement was responsible for the trouble, whereas it was conclusively shown by Faija and others that the magnesia was merely deposited in an inert form from the sea water, the reaction being that the sea water dissolved a certain amount of lime from the cement, and the solution of lime thus formed immediately precipitated the magnesia contained in the sea water. An excess of magnesia is not desirable, but very few cements made from the chalk and clay formations in the Thames and Medway valleys contain more than 1·5 per cent. The cement made from the Lias formations and from the limestones and clays of North Wales, generally contain rather more; in fact, one factory in the latter district, with which the author was connected a few years back, produced a very good cement containing as much as 5 per cent. of magnesia. It is of course preferable that a cement should not contain more than 3 per cent., and the less the better. The reason why a considerable amount of magnesia is dangerous, is that it needs a much higher temperature than lime to enable it to combine with the acid constituents, and therefore an excess is generally in a more or less uncombined state.

Most cements contain a small percentage of potash and soda, or "alkalies" as they are generally classed in an ordinary analysis, but the percentage is so small, and their effect of so little importance, that they are generally not worth estimating separately. Instances have, however, occurred of cements made from the lime waste of alkali works giving anything but satisfactory results, and the only fault that could be found with their chemical composition was a slight excess of alkali. In one particular instance, a pat having been made and left in air in the usual course, a thick white furry efflorescence was found to have been formed on its surface a few hours afterwards, which

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proved to consist chiefly of carbonate of soda. This was evidently due to the water used for gauging having dissolved out the alkali, which would be brought to the surface with the water when the pat was smoothed off with the trowel, and the subsequent setting of the sample absorbing the water, the alkali, which probably consisted of free caustic soda, combined with the carbonic acid in the atmosphere and thus caused an efflorescence.

A great deal has been said and written about "free lime" in cement as forming the chief disintegrating ingredient, but it has by no means been proved that free lime, i.e. lime in an actually free state, really exists, even in an unsound cement. Recent personal research suggests the impossibility of lime, which has been subjected to a high temperature in the presence of acid silicates and aluminates, remaining unattacked thereby, and it is therefore difficult to conceive how "free lime" can exist in a Portland Cement compound. The same research suggests that the truer explanation of what causes subsequent expansion and disintegration in cement, is that a vitreous, unstable high-lime compound is formed, which slakes or hydrates so extremely slowly, that it may be months before visible hydration even commences; but in such cases hydration is accompanied by enormous expansion, the increase in bulk amounting to many times the original size of the mass, sufficient to cause the disruption and total disintegration of the previously set particles in the cement.

The insoluble residue of a cement indicates the amount of uncombined silica and alumina in the form of sand and clay; and if there is any considerable amount of insoluble residue, it suggests that a bad sandy clay has been used. If, however, the sand in a clay is in a finely divided form, it will be found to combine with the other constituents on calcination, or, in other words, the lime will absorb it,

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unless it is of a very coarse nature. The insoluble residue of a cement should not exceed 2 per cent., but as it merely represents so much inert matter, it really is not of vital importance. The estimation of the insoluble residue is held by some to afford an indication of the perfection or otherwise of the mechanical mixture and subsequent calcination of the raw materials, but the author's experience is that the difference in this respect between a well-washed and badly washed cement is so slight that it really affords very little guidance.

With the object of determining the percentage of insoluble residue in cement clinker at different degrees of calcination, samples were procured from four different works on the Thames and Medway and examined in this particular, the results of which are given in the following table :—

Clinker from	Percentage of Insoluble Matter at Different Degrees of Calcination.			
	Very much Under-burned.	Under-burned.	Slightly Under-burned.	Well-burned.
Cement works A .	2·67	nil	nil	nil
„ „ B .	1·93	0·14	nil	0·10
„ „ C .	0·58	nil	nil	nil
„ „ D .	0·28	nil	nil	nil

To ensure comparative results, an average sample of each kind of clinker was taken from the same kiln. The well-burned sample was of a dark porous honeycombed nature, indicating that the calcination had been pushed just to the point of incipient vitrifaction; the slightly under-burned sample was much lighter in colour,

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indicating that the calcination was scarcely completed; the under-burned sample was still lighter in colour and gravity, while the very much under-burned material consisted simply of slurry which had only been subjected to sufficient heat to drive off the carbonic acid, and was almost yellow in colour. It will be seen that the insoluble residue in all the "well-burned," "slightly under-burned," and "under-burned" samples was practically nil, while in only two of the "very much under-burned" samples does it exceed 1 per cent. As all the samples denominated "under-burned" were of such a nature as to produce an utterly unsound and worthless cement, it seems pretty evident that the estimation of the insoluble residue is not much of a guide as to the amount of calcination to which a sample has been subjected. It will be seen from the table on page 73 that the ash of the coke used for calcination consists largely of insoluble matter; and as these samples of clinker were picked specimens, free from the dust of the coke ash, it suggests very strongly that the fractional percentage of insoluble residue usually found in an ordinary cement, is due principally to the ash contained in the fuel used for calcination purposes.

Some users lay great stress upon the amount of carbonic acid which the cement contains, as indicating uncombined lime or insufficient calcination, and specifications are met with which require that the quantity shall not exceed 1 per cent. All cements absorb more or less carbonic acid and moisture from the atmosphere, and the amount will sometimes be considerable, depending, of course, upon the amount of aëration to which they have been exposed. The following experiments, initiated by the late Henry Faija some eight years ago, and completed by the author, may be interesting on this point. A perfectly sound cement, examined immediately on arrival from the

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manufacturers, was found to contain ·25 per cent. of carbonic acid. Part of the sample, designated No. 1 in the following table, was kept headed up in the cask in which it was received, and a part (No. 2) spread out on a tray exposed to the atmosphere in a thin layer. Each sample thus treated was examined for carbonic acid at stated intervals, and the percentage absorbed was found to be as follows :—

After ..	28 Days.	3 Months.	6 Months.	12 Months.	2 Years.	3 Years.
No. 1	·57	1·08	1·57	2·05	2·90	3·21
No. 2	1·82	3·30	4·00	4·90	5·05	5·60

The above cement, tested for tensile strength at similar prolonged periods, carried at three days 325 pounds, at seven days 431 pounds, and gradually increased in strength, till, at the end of three years, the breaking weight was 889 pounds, thus conclusively proving that there was no fault to be found with the cement as regards soundness or the presence of free lime.

Except in corroboration of an opinion already formed from the yellowish under-burned appearance of the sample, the percentage of carbonic acid is not much guide as to the calcination to which a cement has been subjected; moreover, as it merely indicates that the uncombined lime has become carbonated, and therefore harmless, it is a little difficult to understand the importance attached to it by some users.

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CHAPTER VIII.

ADULTERATION.

AT the conclusion of a paper read by the late Henry Faija before the Society of Engineers, in June 1885, the following passage occurs :—

"In the early part of the paper, the author used the word 'adulterant' when referring to the coarse particles of a cement. He refers to it again because the Cement Makers' Union in Germany has lately had a paper submitted to it, being the result of certain experiments by Dr. Fresenius, made with the object of deciding whether or no a cement is adulterated. Dr. Fresenius says that cement has lately been much adulterated with a material so similar to what cement should be, that even chemical analysis fails to detect it, and he, therefore, submits to the Union a number of tests or rather chemical processes by which such adulteration may be detected. The author is glad to say that in his practice he has never yet met with an adulterated English cement, any shortcomings in a cement having been due in all cases to more or less faulty manufacture, or to the use of improper raw materials. As every matter of chemical research, or, it may be said, of testing, connected with cement which emanates from Germany has great weight with many in this country, the author thinks it but right that he should say this much in honour of the English manufacturers, who have not had the opportunities

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of the technical education which is so general in Germany, and which seems, in this particular manufacture at all events, to have enabled the pupil to circumvent the master. . . . . The user may be quite satisfied that when using English cement, he may have a bad or an unsound one, ... but he is not at all likely to meet with an adulterated one."

Although, unfortunately, the author cannot endorse the above paragraph in its entirety, he will say, in justice to the London manufacturers, that, with the exception of two or three small works who use and advocate the admixture of Kentish ragstone ground up with their cement, he has not met with a case of adulteration of cement made in that district. The makers in question who use Kentish rag only represent an extremely small proportion of the output of the Thames and Medway, and practically the whole of their manufacture is consumed locally, so that there is justification for the belief that the whole of the cement at present exported from the Thames and Medway is the proper calcined kiln product.

This question of Kentish rag and other admixtures gave rise to a good deal of discussion some ten years ago. The manufacturers above-mentioned claimed that its judicious admixture not only was not an adulteration, but actually improved the quality of the cement. With the object of ascertaining the actual effect of such admixtures, the author instituted a considerable series of experiments on the subject, the results of which are embodied in the paper which he had the honour of reading before the Society of Engineers in November 1896.

Kentish rag is a sandy limestone of the lower Greensand formation, consisting chiefly of carbonate of lime, but containing more or less sandy or clayey matter, its composition varying according to the strata in which it is found.

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The chemical constituents of the particular stone used for the experiments in question were found to be as follows :—

Water	1·00
Insoluble siliceous matter . . .	7·28
Soluble silica	2·75
Alumina	3·70
Oxide of iron	3·34
Carbonate of lime	80·69
„ magnesia . . .	·56

The first series of experiments consisted in ascertaining the effect of admixtures of various proportions of finely ground ragstone upon the tensile strength of four different Portland Cements, both when tested neat, and with three parts of standard sand, the amount of ragstone added varying from 2 to 50 per cent., and the tests extending from seven days to twelve months. The results showed that although in some instances the neat briquettes were slightly improved by the admixture, the 3 to 1 sand briquettes generally showed a diminution in strength, the diminution ranging from 6 to 19 per cent., according to the amount of the admixture used. It was further found that the weakening effect of the ragstone was greatly intensified when the briquettes were left entirely in air, and also when gauged with, and placed in, sea water. The effect of an admixture of finely ground sand was also tried in one instance, and the results suggested that further experiments with that substance would be of interest.

A further series of experiments with three other cements corroborated the results obtained in the first series, viz. that the 3 to 1 sand briquettes were invariably reduced in strength by the ragstone admixture ; that an admixture of finely ground sand with cement was practically of the same value as an admixture of ragstone ; and

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that by leaving the briquettes entirely in air, and also when used with sea water, the prejudicial effect of the ragstone was much more marked. Altogether the experiments comprised some two thousand briquettes, and conclusively showed that inasmuch as the admixture of Kentish rag reduces the adhesive power or cementitious value of the cement, it is merely a diluent or adulterant.

An adulterant, which from personal experience seems to be rather extensively used by certain north of England manufacturers, is blast furnace slag, probably owing to its being readily obtainable and being somewhat of the same colour and appearance as the cement clinker. In the absence of any conclusive independent evidence in its favour, the author is of opinion that this material is a mere diluent or adulterant, inasmuch as by itself it has no cementitious value. By some it is claimed to be an improvement, the fact that slag "meal" mixed with slaked lime produces a slag cement, being brought forward as an argument in support of this contention; but, inasmuch as Portland Cement is an entirely different material to lime, both in its chemical composition and the amount of calcination to which it has been subjected, it is difficult to see how any parallel can be drawn between them.

With reference to the means of detecting admixtures of these materials, viz. Kentish rag and slag, experience has proved that the ordinary tests for tensile strength as a general rule, fail to indicate their presence, even when in considerable quantity. This more especially applies to the neat tests of well ground cements; as is shown in the paper above referred to, as much as 30 per cent. of fine sand may be added to a cement without appreciably affecting its strength when gauged neat. The 3 to 1 sand test shows a marked diminution in strength when the sample contains an appreciable quantity of such inert admixture,

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but this by itself is not sufficient to enable a decided verdict to be given as to whether a cement is pure Portland Cement or not. Perhaps the most certain means of detecting added impurities is by chemical analysis, though some of the slags so nearly approximate the chemical constituents of a normal Portland Cement, that by itself a chemical analysis is not sufficient to determine their presence with certainty. Taken in conjunction with chemical tests, the microscope will be found of great value for this purpose; such means of detection will be referred to later.

With regard to Kentish rag, a chemical examination of a fairly simple nature is sufficient to detect its presence. This substance, consisting of a more or less impure carbonate of lime, effervesces freely on the addition of hydrochloric acid, and therefore a cement containing any appreciable quantity of it will exhibit similar characteristics according to the amount of carbonate present. A convenient method is to prepare a weak solution of acid in a glass dish, and drop the cement into it, a small quantity at a time, from the point of a pen-knife; if the limestone is present in any appreciable quantity it will, of course, cause considerable effervescence. As, however, all well-matured cements absorb more or less carbonic acid from the air, care must be taken that the effervescence, due to the liberation of the carbonic acid thus absorbed, is not confounded with that due to the presence of ragstone, though a very little experience enables the operator to distinguish between the two. When Kentish rag is present, the effervescence is more prolonged, owing to the acid slowly attacking the coarser particles of the limestone, whereas with pure cement only the finest portions or the outside of the coarser particles absorb the gas from the air, and the effervescence is therefore practically instantaneous.

Referring to the detection of the slag admixtures by

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chemical means, as before stated, some slags so nearly resemble cement in their chemical composition, that an ordinary statement of analysis will often fail to demonstrate their presence. One peculiarity that may be noticed, however, is that when dropped into a weak solution of acid, as described in the examination for Kentish rag, the mass has a tendency to blacken, and also to evolve rather a marked quantity of sulphuretted hydrogen gas. As, how-

FIG. 85.

ever, a good many cements perfectly free from added slag sometimes evolve noticeable quantities of this gas, it must be taken as a corroborative test only, and not as conclusive by itself. There is also a physical peculiarity which may be noticed in many cements containing slag, and that is, after being gauged into pats or briquettes in the ordinary way, and placed in water as usual, when broken in the testing machine, or otherwise, the freshly fractured sec-

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tion has a peculiar dark green colour, probably owing to the presence of sulphur or sulphide in the slag. This dark green colour, however, fades to the normal grey when exposed to the air for a few hours.

Taken in conjunction with the usual mechanical and chemical tests, the microscope will be found of the greatest value in determining the presence of foreign added materials in cements; in fact, it is possible in most instances to

FIG. 86.

form a fairly accurate opinion from a microscopic examination alone, as to whether such admixtures are present in any appreciable quantity. For the purposes of a microscopic examination it will be found most convenient to take the coarser particles of the powder, viz. those particles which pass through a 76 sieve and are retained on a 120 sieve. The particles, of a pure, well-burned cement clinker of this size, examined with a low power (say a 1-inch

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objective) are dark, almost black in colour, somewhat resembling coke, and possess the well known spongy, honeycombed appearance, characteristic of cement clinker. The ordinary cement of commerce, unfortunately, does not always consist of thoroughly burned portions only, a more or less appreciable quantity of insufficiently calcined material finding its way into the mills. The appearance of these insufficiently calcined particles, examined in the same way,

FIG. 87.

is practically the same in shape and structure, but the colour, instead of being black and coke-like, is of a light brown semi-transparent nature, resembling gum arabic. The particles of an ordinary commercial cement, therefore, composed of clinker more or less well burned, examined under these conditions, range in appearance from a light brown, semi-transparent, porous substance to the coke-like mass above described. It may be added here, that the author

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has always found the shape of these particles, whether ground by millstones or ground by edge-runners, of a more or less rounded nature, and he is therefore of opinion that, although there may be minute differences in the shape of the particle, the reason a cement ground by millstones, and leaving a certain percentage on a certain sieve, always has better cementitious qualities than one ground to a similar degree of fineness by edge-runner mills is not so

FIG. 88.

much due to difference in shape of grain as is generally supposed—in the former case angular, and in the latter case rounded—but to the fact that the millstones produce a greater proportion of impalpable powder or flour.

The appearance of Kentish rag, viewed under the microscope under the foregoing conditions, is of a white, rounded, semi-transparent nature, and has none of the peculiar honeycombed appearance of cement clinker; it

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will, therefore, be readily understood that its detection by means of the microscope is a fairly simple matter. By permission of the Society of Engineers, the photo-micrographs prepared for the paper previously referred to are reproduced in Figs. 85 to 90, and they clearly show the difference microscopically between pure cements and those containing admixtures. Of course, the main defect of photography for this purpose is that the colour of the

FIG. 89.

object is not reproduced, and from the description previously given of the difference in colour of the well-burned and under-burned portions, this defect will be readily appreciated. In all of these photographs the substance has been prepared by sifting through the sieves previously mentioned, viz. 76 and 120, so that the actual diameter of the particles is about ·006 of an inch. Fig. 85 is a photo-micrograph of the Kentish rag used in the experiments, and

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Fig. 86 of a piece of well-burned clinker from the Rugby district. Apart from the difference in structure, one is nearly black and the other almost white, as shown. Fig. 87 is an ordinary cement of commerce, in which, it will be observed, the under-burned portions show up rather lighter than the rest. Fig. 88 is the same cement as No. 87, with 20 per cent. of Kentish ragstone added. The admixture is readily recognisable from its white, semi-transparent, rounded ap-

FIG. 90.

pearance, in contradistinction to the almost black porous clinker. It may be stated here, in passing, that in preparing these photographs it was found that, if the cement had attained any age, the flour or impalpable powder had a tendency to become hydrated by the moisture in the atmosphere, and cling to the outer surface of the coarser particles; consequently, when these particles were illuminated for the purpose of photography, the adhering flour gave the par-

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ticle a lighter appearance than it really possessed. Fig. 89 is another cement containing ragstone ; this sample was procured from a firm of manufacturers who use and advocate the use of that mixture. In this case, also, the admixture is readily discernible both by its colour and structure. Fig. 90 is a cement containing a large admixture of slag. In this particular instance the non-reproduction of the colour of the object is a great disadvantage, as the colour of the substance, to use a rather juvenile simile, resembles more the saccharine concoction sold by confectioners as "mixed sweets" than anything else it can be compared to ; this is perhaps rather an unwonted metaphor for a technical treatise, but it describes exactly its appearance. It will be noticed also that the fracture of the slag is of an angular, almost flaky nature, some of the particles having a sharp knife-edge resembling fractured flint.

Care must be taken also, in examining a cement for adulteration under the microscope, not to confuse the lighter coloured natural cements, which are now largely imported from Belgium, with artificial cements containing admixtures of ragstone or slag. Owing to the natural cements containing very little iron (and what little they do contain being probably unevenly distributed throughout the mass), and also being somewhat lightly burnt, they contain a great many light particles, ranging from almost white to the proper dark green clinker colour ; these light-coloured particles are, however of the same porous spongy structure as the clinker, and a little practice will soon enable the operator to distinguish between a Belgian natural cement and an adulterated artificial cement.

The two substances previously mentioned, viz. Kentish rag and slag, are the only wilful admixtures which the author has met with so far as regards English manufacturers, though there are, of course, what may be termed accidental

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impurities, such as an occasional piece of the fire-brick lining of the kiln, which maybe falls in with the clinker, and is thus carried to the crusher unnoticed. Where coal is used for calcination, there is also another source of accidental or rather unintentional adulteration, as it sometimes happens that a piece of coal becomes embedded in the mass of clinker, and, probably owing to its being deprived of the oxygen necessary for its proper combustion, is not consumed. When a hard burr of clinker is broken up to be fed into the crushers, a piece of coal may often be seen embedded in the heart of it. This coal is, of course, ground up with the rest of the cement, and if not visible to the naked eye, may often be detected in the ground material by means of the method of microscopic examination previously described. The amount of coal thus unconsumed is, of course, infinitesimal, but it is sometimes sufficient to be noticeable in the cement briquette; and cases have occurred in which cement has been rejected by the engineer on that account.

In conclusion, it may be pointed out that, from a manufacturer's point of view, the use of slag or other adulterant is a double source of profit; in the first place there is the profit derived from the addition of a less valuable material, and secondly it results in an increased output, which consequently further reduces the cost per ton for establishment and other fixed charges. Where the admixture amounts to 33 per cent., as is the case at one factory, this latter is by no means an inconsiderable item.

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CHAPTER IX.

SPECIFICATIONS.

THE author feels that a work of this description would scarcely be complete without some reference to cement specifications, and in this chapter he proposes to point out some of the contradictory clauses which such documents sometimes contain ; clauses which are no good whatever to the user, and unnecessarily hamper and bind the manufacturer.

The most usual error which the writer of a specification makes, is to pick out what he considers to be the most important clauses in other specifications and incorporate them in his own. The consequence is, that the specification thus drawn up is often an absolutely impossible one to work to, and one with which no manufacturer could properly comply. For instance, it is unanimously admitted that fine grinding is a very desirable quality in a cement, and also that a heavy weight per bushel indicates a thoroughly burned cement. These two qualities are therefore demanded in the same specification, and a finely ground cement is specified, together with a very heavy weight per bushel, the writer probably being altogether ignorant of the fact that a finely ground cement is of necessity a light weighing one, the weight decreasing in direct ratio to the fineness.

Taking the usual items of a specification in order, in the face of the discussion which has recently taken place

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with regard to adulteration, it is perhaps well to specify that the cement shall be pure Portland Cement, but it is a little difficult to understand why some users should go further, and add that it shall be manufactured on the Thames or Medway. Personal experience has shown that equally good cement is manufactured at some of the factories in other parts of England, as at those on the Thames and Medway; and, unless there is some special reason for inserting such a clause, surely it cannot matter where it is manufactured, so long as it is of good quality and complies with the conditions imposed by the specification.

With reference to fineness, again, contradictory clauses often occur. For instance, a specification lately came before the author in which 6½ per cent. was allowed on a 50 × 50 mesh sieve, but there was to be no residue on a 40 × 40. The writer of this specification probably did not realise the fact that, with a residue of 6½ per cent. on a 50 sieve, the residue on a 40 would certainly be as much as 5 per cent.; and therefore, in order, to get the sample to all pass a 40 sieve, it had to be ground to leave less than one per cent. on a 50; the clause specifying the residue on a 50 sieve might have been omitted altogether without in any way detracting from the value of the specification. Unless the very finest sieve is used, such as the 180 × 180, the author is far from recommending that the fineness indicated by one sieve only should be taken, as that might lead to erroneous conclusions as to the actual fineness of the sample. For instance, two cements may leave the same amount of residue on a 50 or other comparatively coarse sieve, and yet one may contain the proper proportion of impalpable powder or flour and the other practically consist of nothing but fine grit. The two following cements, both of which were recently received from the same user for examination and report, may be quoted as an instance of how

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delusive the residue on a 50 sieve only may be as to their relative value :—

—	Fineness.				Tensile Strength.			
	Residue per cent. on Sieves of Meshes per Square Inch.				Neat Cement.		3 Parts Sand to 1 part Cement.	
	50	76	100	180	7 Days	28 Days	7 Days	28 Days
					lbs.	lbs.	lbs.	lbs.
No. 1	6·0	23·0	33·9	50·0	576	648	138	192
No. 2	5·6	15·6	24·6	34·0	693	766	223	285

It will be noticed that both cements have practically the same residue on a 50 sieve, and yet 50 per cent. of No. 1 consists of fine grit that will not pass a 180 sieve. The immense difference between the residue on the 50 and 76 sieves also suggests that the clinker was reduced by edge-runners or a similar method of grinding, in conjunction with excessive sieving, i.e. repeatedly passed under the edge-runners and cracked until fine enough to pass (say) a 40 sieve, thus producing little or no flour. No. 1, again, shows a very satisfactory tensile strain when gauged neat, yet, owing to absence of flour, its cementitious value or power of cementing together particles of sand, as indicated by the sand test, is entirely disproportionate to its power of cohesion as indicated by the tensile strength of the neat briquettes. No. 1 also possessed the peculiar harsh, "short" and gritty feeling under the trowel which is always an indication of an indifferently ground cement, or rather one containing very little flour.

As has been noticed in the chapter on fineness, the thickness of the wire of which the gauze is composed naturally

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affects the size of the openings of the mesh. A specification for important harbour work in the North contains the following clause: "The sieves to be made of brass wire, ·005 inch in diameter for the 50 sieve, and ·007 inch in diameter for the 76 sieve." This may be a very simple method of specifying the thickness of the wire, but to have thicker wire for the finer sieve is entirely reversing the usual order of things, and altogether contrary to common sense. By this specification the width of the opening of the mesh of the 76 sieve is reduced to about ·006 of an inch, instead of about ·009, as in the sieve of standard mesh. This would make an enormous difference in the result obtained, the size of such opening being practically the same as that of a 110 sieve of standard thickness of wire; and consequently the material would have to be ground considerably finer than appears necessary from a casual examination of the clause.

In most specifications the initial set of the cement is ignored altogether, and as the initial set is by far the more important of the two, this omission is very much to be regretted. Whilst duly appreciating the advantage of having some knowledge as to the ultimate hardening properties of a cement, surely it is of as much importance to know when it commences to set, so that an opinion may be formed as to how long it may be manipulated without risk of damage to its setting properties. So far as regards setting properties, the most convenient cement for general use is one which has a moderately slow initial set, so as to allow plenty of time for proper manipulation, and which hardens rapidly after the mass is in its allotted position, so as to permit of the work being proceeded with quickly. Specifications are sometimes met with which require that the cement shall not take less than so many hours to set hard, which is a manifest absurdity; so long as the initial set is sufficiently slow to permit of the

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proper manipulation of the cement, the quicker the final hardening, the better for the progress of the work. An instance was brought to the author's notice in which a cement was being used in a tropical climate, and consequently, its initial set was thereby considerably quickened. Complaint of its quick-setting nature was made to the authorities at home, and as the only clause in the specification was to the effect that the cement should not set hard in less than so many hours, particular attention was paid to that test; the result was, that although in many instances the initial set was slow enough for all reasonable purposes, the inspector rejected several parcels at the manufacturer's works, and would not authorise their shipment on account of the cement having too quick a final set, which was of course altogether beside the question. If its initial set had been too quick, its rejection would have been proper and reasonable, but to reject it on account of its having too quick a final set seems the height of absurdity. In specifying the time of set, it is also advisable to mention the temperature at which the test shall be made, for, as shown by the table on page 253, the setting of cement is largely affected by climatic influences. Except in the specifications drafted by the late Henry Faija, the time of initial set is very rarely specified, the usual vague wording being that: "It shall not set in less than —— hours, nor take more than —— hours to set."

The following clause in a specification lately put forward may be quoted as an instance of the delightfully vague manner in which the setting properties are sometimes specified. "Setting properties.—Pats freshly made will be tested with weight of one pound pressing on an area of cement equal to that of a circle $\frac{1}{16}$ inch in diameter; should no impression be made upon the surface the cement will be accepted." It will be noted that there is absolutely

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no time indicated as to how long after gauging, the test is to be applied; "a freshly made pat" is an extremely elastic term, and might reasonably be construed to mean anything from ten minutes to ten hours. Such a clause is of course utterly useless, and it is a little difficult to understand what the writer of the specification really intended to convey. Of course in large works, where the cement can be properly stored and matured before use, the clause as to initial set is of no particular importance, as the setting properties may be modified to any desired extent by prolonged aëration.

With reference to soundness, the Faija test is very generally specified, and no better or surer means of estimating this all-important property is in use. As before stated, the usual cold-water tests are not sufficiently reliable, to say nothing of the time requisite to carry them out, while, on the other hand, the Deval and similar tests err on the side of severity. The author recently had to test a shipment of cement for important work abroad, in the specification for which the following clause occurred with reference to soundness:—

"Three pats to be made of neat cement, two or three inches in diameter and about half an inch thick in the centre and with very thin edges.

"1. Pat, when set perfectly hard and placed in cold water, should adhere to the glass and show no cracks or distortion.

"2. Pat, allowed to set hard for three hours in a moist air at 200° F., and then placed in boiling water for twenty-four to forty-eight hours, should adhere to the glass, and show no cracks or distortion.

"3. Pat, left in air, should adhere to the glass and show no cracks or distortion, and be of a uniform bluish-grey colour."

In addition to the above, the tensile strain demanded

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was very low—only 300 lbs. per square inch at seve
Such a specification really asks for a weak, over-
cement, and the manufacturers had to prepare a
specially low in lime to enable it to pass the exce
severe boiling test. By so doing they experience
difficulty in obtaining the specified "uniform bluis
colour," the comparative excess of clay having a te
to render the cement somewhat brown and "foxy."

In the clause relating to tests for tensile strength it
specified that a certain amount of water shall be us
gauging, but this is not a wise proviso to make, inasm
the quantity required for properly gauging cement
with almost every sample. One cement may req
much as 24 per cent., while another would be abs
drowned by using 18 per cent. In every case the mi
of water necessary to bring the cement to a plasti
should be used, and the specification should theref
worded accordingly. A rather amusing case oc
a short time ago, in which 10 per cent. of wate
specified for gauging neat briquettes. Evidently the
of the specification had read somewhere that 10 pe
was the amount used for making briquettes, but h
altogether omitted to notice that they were compo
three parts of sand to one part of cement. The
was that the neat cement with only 10 per cent. of
was scarcely damped, and as it consequently did nc
properly into the moulds, the greater part of the
amount required to fill the moulds could not be g
them. Briquettes gauged with a sufficiency of wat
20·13 per cent., carried just double the strain of those
were starved, so to speak, for want of water.

Specifications are sometimes met with which a
cidedly ambiguous as to the time which is to elapse be
the gauging of the briquettes and their immersion in

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The following or a similar clause is frequently to be met with: "Neat briquettes, after being kept in water seven days, shall carry at least —— lbs. per square inch." This might be construed to mean that the briquettes are to be placed in water immediately after gauging and before they are set; if kept in air for twenty-four hours, as usual, before being placed in water, it would become an eight days' test, viz. one day in air and seven days in water.

A somewhat similar clause is the following, which specifies: "That the cement must be capable of maintaining a breaking weight of not less than —— lbs. per square inch seven days after being made in a brass mould and immersed in water during the interval of seven days." This clause evidently intends the briquettes to be plunged in water immediately after gauging, but it is decidedly ambiguous, and might be construed into seven days in water after the usual interval of twenty-four hours in air, i.e. an eight days' test altogether. As this would of course give the cement a longer time to harden, it is the construction the manufacturer would probably prefer to put upon it.

The following is a clause of a similar ambiguous nature; as the cement in question was for shipment to Mexico, it is probably a translation from the Spanish, the translator evidently not being familiar with the usual technical terms. "The briquettes formed from this cement taken indiscriminately from different barrels, soaked in water as soon as they may have attained a sufficient consistence, shall resist at the end of seven days of soaking a minimum tensile strain of —— lbs. per square inch." This also might be construed into an eight days' test, but at all events it involves more than the usual seven days from the time of gauging, everything depending upon how long the cement takes to "obtain a sufficient consistence" to bear "soaking." The obvious way to avoid such ambiguity is to state plainly

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that "briquettes placed in water twenty-four hours after gauging shall carry an average tensile strain of not less than —— lbs. at the expiration of —— days from the time of gauging." It is also important that the briquettes should be tested immediately after being taken out of the water, or at all events within a very short time; if they are left to air-dry too long the breaking strain will be materially reduced. The specification of a well known engineer contains a clause to the effect that the briquettes shall be placed in water twenty-four hours after gauging, left there for six days, and then taken out and allowed to air-dry for a further two days before being tested, i.e. nine days altogether from the date of gauging. As the result of recent experiment, the author found that cement treated in this manner would only carry 289 lbs. per square inch, whereas when tested at the expiration of the seventh day, immediately after being taken out of the water, the strain developed was 521 lbs.

The matter of increase in strength between the different dates of testing is a most important feature, and the author quite agrees with those users who make a point of specifying a certain increase or percentage of increase. In this matter, however, it is possible to defeat the object of the specification, as occurred in a certain instance. In order to ensure that the cement should possess a good growing power or increase in strength with age, a maximum strain at three days and a minimum at seven days was specified, but the three-day maximum was so low that the cement had to be artificially weakened in order to comply with the specification. The same object would have been attained and an infinitely better cement secured if the minimum at each date had been specified, with a minimum percentage of increase between those dates.

The following is an instance of how slight an omis-

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sion may altogether nullify the intention of a specification The cement for some important work in the Colonies was to be inspected previous to shipment, and to ensure its being thoroughly aërated before being packed, the specification contained a clause to the effect that the bulk was to be turned over twice before shipment, the evident intention of the writer of the specification being that at least two or three days should elapse between each turning. No mention, however, of such an interval was made in the specification, and therefore when the manufacturers were pressed for shipment, they simply had the bulk turned over twice within a few hours and packed up at once. It had been turned over according to the terms of the specification!

While fully appreciating the fact that special requirements necessitate special specifications, the following form of specification is submitted as one which is fairly simple, which would ensure the delivery of a good sound cement suitable for almost every purpose, and which no first-rate manufacturer would object to work to :—

Model Specification for General Purposes.

The whole of the cement shall be pure Portland Cement, and shall conform to the following tests :—

Fineness of Grinding.—To be such that when sifted through a standard sieve having 50 holes per lineal inch, there shall not be more than one half per cent. (½ %) by weight of residue; when sifted through a sieve having 76 holes per lineal inch, there shall not be more than five per cent. (5 %) of residue; and when sifted through a sieve having 100 holes per lineal inch, there shall not be more than twelve per cent. (12 %) of residue.

Time of Set.—A pat of neat cement gauged with the minimum of water at the normal temperature (60° F.) and placed on a glass

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or other non-porous slab, shall not commence to set in less than eight minutes, or take longer than five hours to set hard.

Soundness, or freedom from expansion and contraction.—A pat submitted to moist heat and warm water in the Faija apparatus for soundness at the usual temperatures, viz. 110° and 120° F. respectively, shall show no cracks or signs of expansion after twenty-four hours.

Tensile Strength.—Briquettes of neat cement, gauged with the minimum of water on a non-porous bed and placed in water twenty-four hours after gauging, shall carry an average tensile strain of not less than 350 lbs. per square inch after three days, 450 lbs. after seven days, and 550 lbs. after twenty-eight days from the time of gauging.

Briquettes composed of three parts of standard sand to one part of cement, by weight, treated as above, shall carry an average tensile strain of not less than 150 lbs. per square inch at seven days, and 250 lbs. at twenty-eight days from the time of gauging; but no matter how much greater strength may be developed at the earlier dates, both neat and sand briquettes must develop an increase of at least 50 lbs. between each date.

In Appendix No. III. will be found a complete copy of the Standard Specification recommended and just issued by the Standards Committee of several British Engineering Institutions. It follows somewhat closely the general lines laid down in the author's suggested model specification; the tensile strength demanded is somewhat lower, but since the percentage of water is rather higher, the quality would be about the same in the end. The test for soundness adopted, i.e. the Le Chatelier boiling test, is unnecessarily severe, and frequently condemns a good sound cement; the Faija test, which is based on 20 years' practical observation, equally safeguards the user without needlessly rejecting a sound constructive material.

For comparative purposes the German Standard Rules

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for the uniform delivery and testing of Portland Cement, and also the specification issued by the French Ministry of Public Works, are given in Appendices IV. and V. respectively. It is rather a significant fact, in view of the foregoing remarks as to the undesirability of the boiling test for soundness, that the German specification omits accelerated tests altogether, the authorities in that country having decided that they are of more than doubtful value.

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USE OF PORTLAND CEMENT.

THE uses to which Portland Cement may be applied are so numerous that their enumeration would be tedious. The author, therefore, in this part of the work proposes only to glance at them in passing, and to point out some of the chief causes which give rise to unsatisfactory work when executed with that material.

The principal characteristic which renders Portland Cement such a valuable material to the engineer and those in charge of constructive work, is its hydraulic property or power of setting and hardening under water, or what Pasley in his day would have called its property as a "water cement." This property, in combination with its great strength, renders it an invaluable material for dock and harbour construction, and many fine examples may be found around our coasts of its employment for work of this description.

The first care of a user of cement should be to ascertain that it is not too new or fresh for immediate use. It is impossible for the manufacturer of a large output to provide sufficient warehouse room to thoroughly mature the whole of his product. The initial cost of such a structure would entail a heavy outlay, and to cover the first cost of this would result in a greatly increased price to the consumer. Theoretically, of course, Portland Cement should be ready for use immediately after it leaves the millstones,

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or whatever comminuting machinery may have been used for its final reduction, and although in some cases it may be perfectly safe to use cement under those conditions, as a general rule it will be found advisable in all work of importance to thoroughly mature it before use. By thus maturing, any chance particles of free or loosely combined lime which the cement may contain, have an opportunity of becoming hydrated or air-slaked, and thus purging themselves of their obnoxious properties.

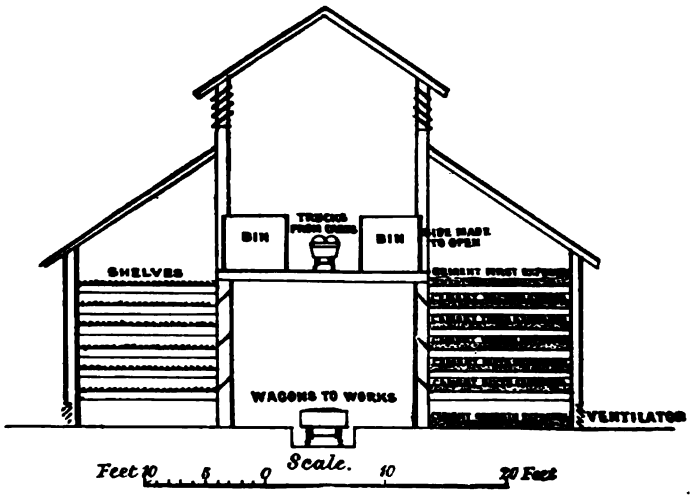

FIG. 91.

On large and important works, engineers who have had considerable experience in the use of cement, often take special precautions to ensure the cement being thoroughly matured before use, and in such cases special stores and maturing sheds are erected for that purpose. Fig. 91 shows a very ingenious contrivance adopted by Mr. G. F. Deacon for maturing the cement used in the construction of the Vyrnwy masonry dam for the Liverpool Water Works.*

* 'Proceedings, Institution of Civil Engineers,' vol. cxxvi. p. 44.

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The working of this method of aeration he describes as follows :—

"Most of the area of the cement warehouse was occupied by six tiers of shelves 2 feet apart, consisting of 10-inch boards, shown on a larger scale at Fig. 92, lying loosely across timber joists and stiffened with cross battens. On

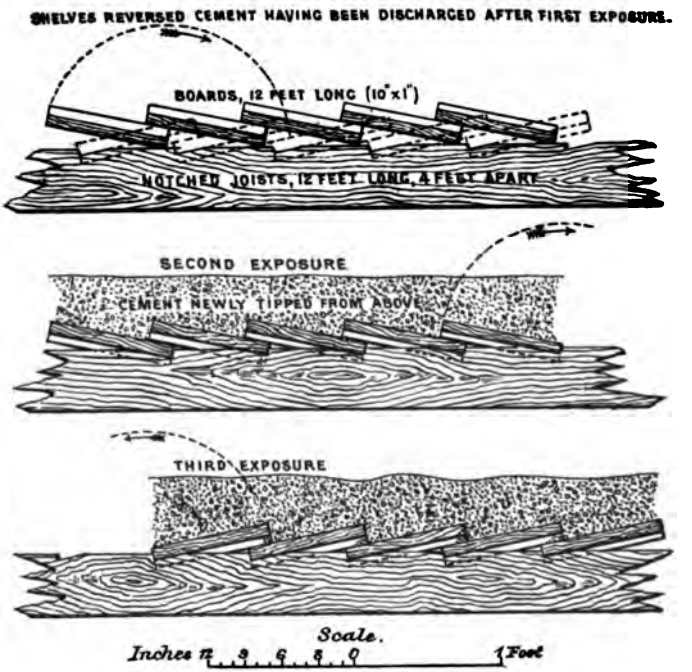

FIG. 92.

the upper floor between the shelves was a high-level narrow-gauge tramway, upon which the sacks of cement were brought in on trucks. From the trucks the cement was discharged into bins, and from these it was shovelled through side openings over the upper tier of loose boards to a thickness of 3 inches or 6 inches. One or two days later, two men passed respectively along the two ends of each set of

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boards, shown in Fig. 92, and tipped them up one by one. The cement then lay very lightly on the next lower tier, from which it was similarly tipped to the next, arriving on the lowest floor after six very complete turnings and continuous exposure in thin layers during one to three or more weeks as might be found desirable."

In the use of such a method of maturing as this, care would have to be exercised during damp weather against damage from over exposure, as if the cement were exposed too long to an atmosphere laden with moisture, the exposed portions of the mass would become coagulated, or what is known as air-set, by which a great part of its vitality would be lost. The author was recently informed by an engineer who had used Mr. Deacon's method that he found the cement in some cases had become greatly deteriorated on this account; but if proper care is exercised there is no doubt that an improved cement would be obtained; and if similar precautions as to thorough aëration were always taken, failures in cement work would rarely be heard of.

Another effect of aëration or exposure of cement is to render it slower setting, and this sometimes produces an important improvement. Some cements, more especially the very finely ground ones, are extremely quick setting when first received from the manufacturer, in fact, so much so, that if used immediately, they would commence to set before manipulation could be completed, thus causing an inferior result. By judicious maturing, part of the aluminate of lime, which is responsible for the setting of cement, becomes hydrated by the moisture in the atmosphere, and thus its setting properties are correspondingly modified. As a rule cement sets less quickly when mixed with aggregate than when gauged neat; from personal observation it has generally been found that a mortar composed of 3 parts of sand to 1 part of cement has an

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initial set about three times that of a neat cement. This remark of course applied only to the use of dry sand and aggregate. If, as is very often the case, the sand or aggregate is wet or moist when mixed with the cement, it is very probable that, owing to the great avidity which cement has for water, it will absorb some of the moisture from the sand during the usual preliminary operation of turning dry, and thus become partially hydrated and lose some of the vigour of its setting properties.

In addition to the other advantages of thorough maturing and aëration, it will be found that the cement increases considerably in bulk, owing to the absorption of moisture and carbonic acid from the atmosphere. In the course of a recent discussion on the subject, a well-known harbour engineer stated that, from experiments he had made, the increase of bulk due to aëration resulting from six turnings amounted to as much as 6 per cent. As the proportions of cement and aggregate are generally determined by measure, this would be an important item to a contractor, and would more than repay the cost of turning.

In order to secure first-class work, the user cannot be too particular in his selection of aggregates, more than one case of unsatisfactory work being traceable directly to the use of a dirty, ill-proportioned aggregate. Loam or dirt is the greatest enemy of cement, and a very small quantity of loamy matter adhering to the aggregate is sufficient to materially weaken the concrete ; since the cement could only cling to the surrounding dirt, and would have no proper adherence to the stone, it would naturally give way on the least stress. The extreme care which is exercised by all makers of concrete paving slabs and other purpose made goods, to thoroughly wash their aggregate, not only to remove all loam or dirt, but also the fine dust produced

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from the crushing of the stone, may be instanced in strong corroboration of this view. In addition to permanently weakening the mass, the presence of loam also renders the cement perceptibly slower setting, so much so as often to be a serious disadvantage.

The weakening effect upon concrete of the fine dust resulting from the crushing of the stone, was recently brought prominently into notice in the author's testing room while examining the comparative value as a matrix, of good sharp sand, and fine limestone screenings, viz. that which passed through a $\frac{3}{8}$-inch square mesh. The sand was remarkably clean, only containing 0·2 per cent. of loamy matter removable by washing. The limestone screenings, on the other hand, were found to lose 20 per cent. of fine dusty matter, and when wetted before washing, had a very muddy appearance. Comparative tests for tensile strength were made of each of the washed and unwashed materials, mixed in the proportion of 3 parts of sand or screenings to 1 part of cement. The results were as follows, the average of five briquettes of 1-inch section being given in each case :—

		7 Days.	21 Days.
Limestone	Unwashed	180 lbs.	235 lbs.
	Washed	161 „	365 „
Sand ..	Unwashed	137 „	185 „
	Washed	138 „	192 „

It will be seen that the strength of the mortar at twenty-one days was improved as much as 55 per cent. by removing the fine dusty matter, and, moreover, that the washed stone makes a great deal stronger mortar than the sand, a result that is probably due to the fact that the former, when crushed, broke up into flat jagged fragments, which afforded a better "tooth" for the cement than the

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sand, though the latter was a good sharp, fairly coarse sand, of decidedly above average quality.

The best aggregate is that which is sharp and angular, and has a rough surface, forming a tooth or key for the cement to adhere to. Sea shingle, from the smooth rounded nature of its pebbles, although often used, is not an ideal aggregate; the cement having nothing but a smooth round surface to adhere to, cannot exercise the same adhesive power as when the aggregate has a rough surface such as ragged broken stone, therefore if sea shingle is used, it should be first run through a crusher, and it will then give excellent results. The size of the aggregate, if of broken stone, may vary according to the size of the work of which it forms a part, but it should all pass a 3-inch ring, and the greater part of it should pass a 1½-inch ring, according to the size of the sand or gravel that is to be used with it. In large monolithic masses such as dock walls, it will be found economical to incorporate large pieces of stone or "displacers," as they are generally called; if these displacers are clean scrubbed and kept a sufficient distance apart, say 18 inches at least, the strength of the structure will not be affected. The essential feature of all concrete, is that each portion of the aggregate should be thoroughly and equally surrounded by a coating of the cement or matrix, as it is evident that if two pieces of aggregate are in contact, without such intervening coating of matrix, the mass must be thereby weakened. Therefore, by properly proportioning the size of the aggregate, the cement will be able to do more work than if all fine aggregate is used, for it is very evident that the larger the size of the aggregate, within limits, the less the external area of such aggregate to be covered with a coating of cement or mortar. In the same way the use of a very fine sand weakens the cementing power of a cement, for, as

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previously stated, the smaller the particles, the greater the external area of such particles within a given space that has to be covered by the cement. A case of failure, traceable partly to that cause, occurred a year or two ago. The sand in this instance was so fine that 80 per cent. passed through a 50 sieve, and 60 per cent. passed through a 76 sieve; in addition to this, it contained a considerable amount of earthy matter, so that it is not surprising that the results were unsatisfactory.

For water-tight concrete, it is important that the size of the aggregates should be so proportioned that the whole of the interstitial space between them is filled up with the sand and cement mortar, for obviously the more porous the concrete, the less likely it is to prove water-tight. The usual method of ascertaining the interstitial space of any given aggregate is to fill a box of given capacity with it, pour in water until level with the top, and then draw off and measure the water necessary to fill the spaces. Recent experiments by the author in this direction with crushed limestone of various sizes gave the following results:—

	Interstitial space per cent.
Passed 3-in. ring and retained on 1½-in. ring	51·32
„ 1½-in. „ „ ¾-in. „	48·54
„ ¾-in. „ „ ⅜-in. „	43·61

When the stone was crushed in an ordinary Blake stone breaker, the average quantity of the largest size was found to be 24·529 per cent., of the medium size 45·858 per cent., and of the smallest size 18·893 per cent., the remaining 10·72 per cent. consisting of fine crushings and dust. Taking the average of the three sizes so as to be on the safe side, the interstitial space is 47·8 per cent., which means that, in order to fill the interstices of crushed stone

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of such size, 47·8 per cent. of its bulk of mortar would be required. Allowing, according to Mr. Sandeman,* another 10 per cent., so as to ensure each piece of stone being surrounded with mortar, the amount required would be 57·8 per cent. According to the same authority, the volume of dry sand and cement necessary to produce a given volume of cement mortar, is about $\frac{1}{3}$ greater than the volume of mortar when set. Therefore $57{\cdot}8 + \frac{57{\cdot}8}{3} = 77$ per cent. of its volume of dry cement and sand, would be necessary in order to produce a water-tight concrete with these materials. It is hardly necessary to add that the strength of the mortar governs the strength of the concrete, and therefore the less sand used the stronger will be the concrete, provided sufficient mortar is used to fill the interstices. With cement of ordinary fineness, Mr. Sandemann advocates not more than 2 of sand to 1 of cement; therefore the above 77 per cent. of dry cement and sand should consist of 51·3 per cent. of sand and 25·7 per cent. of cement. With the materials before mentioned this would give a proportion of 100, 51·3 and 25·7, or approximately 4 of broken stone, 2 of sand and 1 of cement. In this way the most economical proportions of any given materials, compatible with strength, may be ascertained, and it is hardly necessary to add that once the correct proportions have been ascertained, the quantity of each should be carefully measured in suitable gauges provided for that purpose.

The amount of water to be used in mixing concrete depends entirely upon circumstances, and no hard-and-fast rule can be laid down on this point. As a general rule, however, excess of water is preferable to an insufficiency. Following out the teaching of testing room experience, the minimum of water gives the best results, but of course the

* 'Proceedings, Inst. Civil Engineers,' vol. cxxi. page 219.

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conditions which exist on the works and those which obtain in the testing room are often widely different. For instance, in the testing room, a non-porous mould on a non-porous bed is used, and great care is taken that none of the water used for gauging is abstracted from the cement by any external agencies. In actual work the concrete may have to be laid in a trench on a porous soil, through which some of the water would soak away, or the aggregate may be of a porous nature, and thus again some of the water required by the cement would be extracted. Further, the less water used, the quicker the cement would set, and if a quick-setting cement was being employed, there might be some danger of the paucity of water rendering it too quick setting to be thoroughly and properly manipulated. Where, however, none of these conditions prevail, and there is no fear of any of the water being absorbed by extraneous means, there is no doubt that the minimum of water gives the best results. That point is reached when by ramming and punning the mass, the water just shows on the surface, indicating that exactly sufficient has been used to lubricate, so to speak, the constituents of the concrete, and enable them to flux down together into a compact mass. If more than this amount is used it will be impossible to obtain such a solid concrete, owing to the space occupied by the excess of incompressible water, while, on the other hand, if less is used, the mass will not flux properly, and will thus be rendered porous. Of the two extremes an excess of water is preferable, as less likely to lead to dangerous consequences.

A matter that is scarcely recognised sufficiently among users of cement is the effect of temperature and exposure to weather upon the setting of cement concrete. As has been pointed out in a previous chapter, the setting of cement is a process of crystallisation, and, like most processes of a similar character, is accelerated by heat and retarded by

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cold. In very cold weather, therefore, the concrete cannot be expected to set so rapidly as when exposed to a higher temperature, and *vice versâ*. Several instances of dissatisfaction through want of recognition of this fact have occurred. To give an example, a short time back some concrete forming the foundation for wood paving was laid during a cold snap in October. Of course under these conditions it did not set so rapidly as during the milder weather immediately preceding, and the result was, that as the roadway was urgently wanted for the purposes of traffic, the concrete was condemned, and the whole of the mass had to be pulled up and laid with a quicker setting cement. A piece of the condemned concrete, exposed to a temperature of 60°, was perfectly hard set in a couple of days. In addition to the low temperature prevailing at the time, there was also rather a heavy rainfall, which kept the work continually wet, and, as cement sets more slowly under water than in air, tended in no small degree to further retard the hardening of the concrete—a fact that was proved by those portions which were laid in dry weather being considerably harder than those laid during continual rain.

The views above expressed as to the practical effect of temperature upon the setting of cement have since been amply confirmed by Mr. A. E. Carey, an engineer of wide experience with cement as applied to breakwater and harbour work. In his paper on "Concrete in Relation to Marine Works," read before the engineering conference of the Institution of Civil Engineers in May 1897, he says :—

"The effect of a low sea temperature is a subject which has not hitherto received the notice its importance merits. The author had seven winters' experience at Newhaven, that of 1880–81 being unusually severe; but in carrying on the harbour works now in progress at Hastings (only about 25 miles distant) the experience of last winter

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raised novel issues in this particular. The breakwaters at Hastings are being wholly constructed in mass concrete, and commencing in October last, the setting became so extremely slow that work on the foundation reef was liable to be ploughed up by a moderate sea sometimes days after deposit. The specification is a severe one, and the greatest care was taken in testing. Up to this time nothing of the kind had occurred, and the season was open and normal. Cubes of concrete were then made with, and immersed in, sea-water in the open, the cement being taken from five of the best makers. All gave pretty much the same results, the cement failing to set for days. The retardation of the setting was ultimately clearly traced to the extremely low temperature of the sea, due, doubtless, to the predominance of cold currents flowing down from the North Sea. The sea temperature varied in January last from 37° F. to 38° F.; February 37·5° F. to 40° F.; March 31·5° F. to 43° F., and in April 43° F. to 49° F.

"At Newhaven probably the warmer currents from the Atlantic set up a different set of winter conditions. Observations of the sea temperature as long continued as possible, and some elasticity in the specification, are two important matters where extreme seasonal variations may obtain. A very heavily burned cement is unsuited to winter work under rigorous conditions of temperature."

Of course in this instance the setting would be still further retarded by the salts in the sea water, for, as previously mentioned, Portland Cement sets much slower in sea water than in fresh, though its ultimate strength is quite as great, or greater.

If a freshly gauged concrete is exposed to frost while it still contains uncombined water, the natural consequence is that the water freezes and expands, and causes the disintegration of the mass. The author once had occasion

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to investigate a case of failure of this sort in which freezing was undoubtedly the cause of the mischief, as when the frost broke, exactly the same materials were used for the work with perfectly satisfactory results. A correspondent, writing on this subject from Ontario, remarks: "I have successfully built works of Portland Cement concrete and mortar in this climate in the middle of winter, the thermometer ranging from + 39° to − 20° F., and the work is in excellent shape. I used hot water to the heated sand and added a lot of salt; the water was practically hot brine. In the following spring, and for some years afterwards, a white efflorescence appeared, but its only effect is to appear somewhat unsightly." In England, of course, we do not experience such extremes of temperature as those above described; but it is the general rule to protect newly laid concrete or mortar from the effects of frost, and during very severe weather to discontinue work altogether. The use of a large quantity of salt, as above described, would have the double effect of retarding the setting of the cement and preventing the freezing of the water, and it is only to be expected that its presence would cause a considerable efflorescence on the face of the work.

A high atmospheric temperature, on the other hand, greatly accelerates the setting of cement, and allowances should therefore be made in this respect, during very hot weather or in tropical climates. It is hardly necessary to add that if cement work is exposed to a hot summer sun, especially in very thin coats, such as external wall plastering. there is great danger of the water necessary for the proper setting and hardening of the cement being evaporated, and unsatisfactory results ensuing. In work of this sort it is absolutely essential that the wall or surface to be plastered should be thoroughly wetted before the plaster is applied. otherwise the water necessary for the proper hardening of

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the cement will be extracted, and unsatisfactory work will result.

Another frequent cause of indifferent work is insufficient attention to the setting properties of the cement under treatment. As has been pointed out previously, the setting of cement is a crystallising process, and when the crystals commence to interlock, the fluidity or mobility of the mass is arrested. With quick-setting cements especially, this period is very marked, and it is very evident that if a concrete or mortar is manipulated and worked after this stage has been reached, the bedding or interlocking of the crystals will be broken up, and the strength of the mass materially weakened, the damage done depending on the setting properties of the cement, and on how far setting has progressed before it is finally left at rest.

In a paper read before the Institution of Civil Engineers, in 1887, on "Concrete Work Under Water,"* the late Mr. W. R. Kinniple advocated the use of what he termed "plastic concrete" for such work. This plastic concrete was prepared by mixing the concrete on shore and allowing it to partially set before depositing it under water, by which means it was claimed that in places where a current existed, there was less chance of the cement being washed away from the aggregate. Mr. Kinniple also claimed that by this means the cement lost but little of its original strength, and by adopting this method, the excessive proportion of cement otherwise required to allow for that washed away was avoided. Experiments were quoted showing "that 3½ to 1 concrete after setting out of water for eighteen hours, and then rammed into moulds, will form a monolithic mass when afterwards placed in water; but that the strength of this mass will very much depend upon the time allowed for setting before deposition. If only eight hours elapse between

* 'Minutes of Proceedings Inst. C.E.,' vol. lxxvii., pp. 65, &c.

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mixing and deposition, there is practically no reduction in strength ; but with a longer interval the strength is gradually reduced, until at about eighteen hours it is little more than half." It is needless to remark that the setting properties of the cement would entirely govern the time allowed to set before deposition ; a moderately quick-setting cement such as is often used now for sea-water work would be absolutely ruined if broken up after being allowed to set for eight hours, while a very slow setting one might be left for eighteen hours without detriment, especially in cold weather, when the setting would be still further retarded by low temperature.

This subject was subsequently dealt with in a paper by the late Henry Faija, "On the Effect of Sea Water on Portland Cement." * He preferred to designate Mr. Kinniple's concrete as "reset" concrete instead of plastic concrete. He stated that a "reset" concrete, to be of value, must be made with a slow-setting cement, and it must be broken up and placed or rammed *in situ* at a particular period during its progress of setting. If this is delayed too long, the "reset" concrete will never attain that hardness which it would under proper conditions. His experience of reset cements was that the breaking up of the mass and the re-gauging should be done at the moment when, by ramming, the original water of gauging can be brought to the surface, and that if that time was exceeded, and the concrete, after being broken up and rammed, remained dry, then the result obtained was not satisfactory, and the cement in this condition would undoubtedly be subject to the dissolving action of the sea on the lime. The following experiments made by him with "reset" cements confirmed that view :—

* 'Society of Engineers,' 1888.

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No. 1.—A Cement that Set in One Hour, Neat Cement.

(Second gauging, 45 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging .	482	596	..	..	..
Second gauging.	414	550	..	..	..

No. 2.*—A Cement that Set in Two Hours, Neat Cement.

(Second gauging, 20 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging .	578	682	..	..	..
Second gauging.	†465	†568	..	..	..

No. 3.—The Same Cement Gauged with three Parts of Standard Sand.

(Second gauging, 45 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.		
First gauging .	..	280	284	..	..
Second gauging.	..	†152	†133	..	..

* This is a cement adulterated with slag.

† On the second gauging of these the water or moisture could not be brought to the surface of the briquettes, showing that the setting had proceeded too far for the best results to be obtained on the regauging.

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No. 4.—A Cement that Set in Forty Minutes, Neat Cement.

(Second gauging, 20 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	lbs.
First gauging .	..	586	666	620	738
Second gauging.	..	*648	558	547	602

No. 5.—The Same Cement Gauged with Three Parts of Standard Sand.

(Second gauging, 30 minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	
First gauging .	..	242	304	331	..
Second gauging.	..	*222	202	143	..

No. 6.—A Cement that Set in Four Hours, Neat Cement.

(Second gauging, 2 hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	lbs.
First gauging .	..	657	763	775	784
Second gauging.	..	658	698	757	811

* This cement had become considerably slower setting, and consequently these briquettes were not so dry as those re-gauged for the three, six and nine months.

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No. 7.—The Same Cement Gauged with Three Parts of Standard Sand.

(Second gauging, 2½ hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	lbs.
First gauging .	..	264	320	321	..
Second gauging.	..	230	329	322	..

No. 8.—A Cement that was Two Years Old and took 24 Hours to Set, Neat Cement.

(Second gauging, 18 hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging .	314	453	..	..	..
Second gauging.	326	479	..	..	..

No. 9.—A Cement that took Six Hours to Set, Neat Cement.

(Second gauging, 1 hour after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging .	477	585	..	..	..
Second gauging.	467	529	..	..	..

"The noticeable feature in the foregoing tests is that when a quick-setting cement is used, the 'reset' cement

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always shows a very considerable diminution in s whereas in the slow-setting ones the loss is not and in the one instance, No. 8, when the cem twenty-four hours to set, the re-gauging of the actually increased its tensile strength. The whol results given represent the average of five briq each instance, so that they may be considered represent the value of 're-gauged' cement."

Mr. Smith in 'Correspondence on Concrete V Harbours,' * expresses an opinion which entirely the foregoing views. He says:—"The final set pended upon there being no addition made to the of water absorbed in deposit. When the partly crete was not thoroughly pulverised and refluxe water in deposit, the mass remained porous, and t disintegrated the cement and prevented it from set

Personally, the author is of opinion that a tampering with the setting properties of cement is on dangerous ground. It has been shown by the f quotation that to obtain the best results, partially se must be broken up and re-gauged at a certain not ve defined period during the process of setting, an period is exceeded, great loss of strength resul such purposes as those described by Mr. Kinniple be economical to use cement in the manner which l cates, but, more especially in marine construction method affords an excellent opening for attack by water; it is not at all unlikely that the use of this concrete, intentional or otherwise, is responsible failures in sea-water work, which have occurre occasionally, it is true—but still *have* occurred coasts.

* 'Minutes of Proceedings of the Institution of Civil Engi lxxxvii. p. 214.

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To guard against the possibility of the cement being manipulated after setting has commenced, or as it is generally termed "killed," it is advisable for the clerk of works, or person in charge of the work, to occasionally gauge up a small pat of the cement to be used, taking care that the conditions of temperature and exposure are the same as in the actual work, and, noting any peculiarities in its setting properties, to take precautions accordingly. A cement that would allow a comfortable time for manipulation under ordinary climatic conditions, would be absolutely ruined if worked for the same length of time in very hot weather, such as often occurs during the summer months or in tropical climates. In such cases the only course open to the user is either to further aërate the cement so as to render it slower setting, or to mix the concrete in small quantities, and see that it is in its allotted position before setting commences.

The effect of sea-water on Portland Cement is a question which, some few years ago, caused a considerable amount of anxiety among engineers and others who were using it under those conditions. The failures at Aberdeen Harbour in 1887, and the subsequent reports of Mr. Smith, the harbour engineer, in conjunction with Professor Brazier, of Aberdeen College, went to show that the action of sea water had a decomposing effect upon cement, and in this opinion they were supported by the late Mr. Phillip Messent, engineer to the Tyne Commissioners. After a considerable amount of chemical and physical research by these gentlemen, the failures in question were attributed solely to the destructive action of the sea water upon the cement. It was, however, afterwards conclusively shown that there was some reason to doubt both the quality of the cement used, and also the method of using it, the concrete which failed being of such a porous nature that the water could percolate rather freely

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through it. The point upon which most stress w
the report of the before-mentioned experts, was th
of magnesia found in the decomposed cement ta
the dock walls. Professor Brazier attributed this
water dissolving the lime out of the cement, and
tion of lime thus formed immediately precipit
magnesia contained in the sea water. In orde
roborate his views as to the destructive action of
upon cement, he digested cement in a powdered
sea water, with constant stirring to prevent its se
found that a certain amount of the lime was diss
of it, and a quantity of magnesia deposited. As w
by Faija in a paper on the subject read before th
of Engineers in 1888, the results obtained by this
were scarcely conclusive, for it does not follow tha
sea water decomposes cement when digested in a
unset condition, it will attack it in the same way a
been allowed to set and harden properly in larg
It is well known that cement will set and harde
well in sea water as in fresh water, although
retards its setting. The following figures, taken
above-mentioned paper, may be instanced as sho
comparative effect of sea water and fresh water
setting and tensile strength of Portland Cement.

"Four briquettes were made, two gauged with
and two gauged with fresh water.

No. 1	gauged with	fresh water,	set in	fresh water	in
„ 2	„	„	„	air	in 1
„ 3	„	sea water,	„	sea water	in 4
„ 4	„	„	„	air	in 2

"These having been left respectively in sea w
fresh water for twenty-eight days, were tested f
strength with the following results :—

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No. 1	broke at	.	.	. 595 lbs.
„ 2	„	„	.	. . 540 „
„ 3	„	„	.	. . 690 „
„ 4	„	„	.	. . 650 „

"Several briquettes were gauged with sea and fresh water and tested with the following results, each test representing the average of five briquettes."

Tensile strength at — Days after Gauging.	Gauged with Fresh Water and placed in Fresh Water 24 hours after Gauging.	Gauged with Fresh Water and placed in Sea Water 24 hours after Gauging.	Gauged with Sea Water and placed in Sea Water 24 hours after Gauging.
3 days	365 lbs.	407 lbs.	353 lbs.
7 „	434 „	484 „	429 „
28 „	506 „	560 „	566 „

The main fault of the defective concrete at Aberdeen, apart from the action of the salt water upon it, seems to have been excess of sand, and its consequent extreme porosity. One speaker who had seen the work in course of construction, remarked that it was nothing more or less than a huge filter. Of course, under these conditions, the concrete being of such a weak, porous nature, the water could pass freely through it and dissolve out the lime of the cement, at the same time precipitating and depositing the magnesia, the presence of which led to so much apprehension. A series of experiments on the forced percolation of sea water through concrete,* by Faija, showed that if the mass was only moderately porous, the percolation of water through it had no ill effect, and moreover after a time entirely ceased, owing to the pores being blocked up by the depo-

* 'Society of Engineers,' 1889.

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sition before mentioned. Comparative tests ma
briquettes treated in the ordinary way, and those wl
been subjected to forced percolation from a head of
gave results slightly in favour of the latter.

A very interesting paper on the effect of sea wat
hydraulic cement has lately been communicated
Institution of Civil Engineers by Dr. Michaelis, of
He commences by stating that hydraulic cement
lime contain a considerable amount of unsaturate
combined lime, and that they therefore segregate thi
of lime during the setting and hardening process
hydrate, with the consequence that the set cement
pletely permeated with crystals of calcic hydra
exhaustive series of experiments is given, showi
ordinary Portland Cements of a somewhat full
nature are decomposed by sea water and the salts cc
therein; but that such action is altogether obviated,
strength of the mortar under all conditions imme
creased, if substances containing alumina and h
silica, such as trass and pozzuolana, are added to the
in sufficient quantity to combine with the lime l
during setting. He says: "The action of sea wat
hydraulic cement is chiefly a chemical one, proceedi
the reaction of the soluble sulphates in the sea w
the free lime, or that becoming free in the course
hardening process, on the ferrate of lime, on the al
of lime, and on the silicate of lime, especially such
compounds as are high in lime." He proposes
to the root of the evil, by laying hold at the o
the injurious excess of lime, and converting it to
purpose; this proposal is based upon the fact tha
long upheld, that clinkered Portland Cements, too
calcic oxide and hydraulic limes, may—either in the

* 'Proceedings Institution Civil Engineers,' vol. cxxix. p. 3

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of manufacture or in the preparation of the mortar—be improved, and more especially rendered more capable of withstanding the decomposing action of sea water, by means of such additions as will go to form fresh hydraulic mortar with the excess of lime, or with that which is set free during the hardening process, i.e. with pozzuolanas in the highest sense of the word. Such suitable pozzuolanas are: hydraulic silica itself, opal, infusorial earth, pozzuolanas in the more restricted sense, trass, santorin earth; also further, powdered glass, certain granulated blast-furnace slags, burnt alum-shale, kaolin, brickdust, &c.

"Of all known additions of this kind, the most effective is real trass, on account of the high proportion it contains of the hydraulic factors, and of the excellent quality of that portion of it which acts as sand."

As will be seen in the latter part of Appendix IV., the members of the German Association of Cement Manufacturers undertake not to add any extraneous material whatever to their cement (beyond a trifling amount of 2 per cent. of gypsum or similar material to adjust the setting properties), as they consider any such addition diminishes the value of the cement, and is, therefore, a fraud on the consumer. This resolution was made with the intention of stamping out the wholesale adulteration which was at one time carried on by some manufacturers. Dr. Michaelis, however, strongly disagreed with the sweeping assertion that all additions of a foreign material weakened Portland Cement, and he brings forward the researches above quoted in support of his contention that some substances, viz. those containing hydraulic silica, &c., may be advantageously mixed with cement. The difficulty to be contended with in admitting such admixtures during the manufacture of cement, would be the proper control of the quantities added, and it is very much to be feared that their admission would

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again open the door to wholesale adulteration, which by the energetic action of the German Association has been practically stamped out in that country.

That sea water attacks unset cement, has since been proved by actual experiment, but personal experience shows that it is only attacked on the surface. If a pat of neat cement be placed under sea water immediately after gauging, it will be found to harden well everywhere except for a depth of about $\frac{1}{8}$ inch from the surface, and in a few hours a white deposit, consisting chiefly of magnesia, will be found to have formed on this soft surface. This suggests that quick-setting cement is the most suitable for marine work, as affording less opportunity for the attack of the sea water, and as cement which is first allowed to set is not affected thereby, it seems better, wherever possible, to adopt the block method of construction, so successfully used by the late Sir John Coode at Colombo and elsewhere.

The sack system of construction for work under water, adopted by Mr. Carey at Newhaven and elsewhere, has much to recommend it, inasmuch as it affords less opportunity for the washing away of the cement from the aggregate and the mass is more under control. As, however, Mr. Carey remarks, in the use of large masses by this system, a great deal depends upon the rapid mixing of the concrete, so that the sack may be placed in its allotted position before setting commences, otherwise not only will it not settle down in its place properly, but the strength and homogeneity of the mass will be considerably impaired.

A use of cement that has made tremendous strides during the past three or four years, is in the construction of ferro-concrete or reinforced concrete, in which iron or steel in some form or other is embedded in the mass. Since the

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resistance of cement to tensile stresses is only about $\frac{1}{10}$ of its resistance to compressive stresses, and the tensile strength of steel is about one hundred times that of cement, it is obvious that the judicious use of about 10 per cent. of steel incorporated in such a way to take the tensile stresses, will equalize the power of resistance to both tensile and crushing stresses, and thus greatly increase the constructive value of the mass. One of the earliest methods of making use of this combination of steel and concrete, is the Monier system of construction, in which steel wires are embedded in the mass in the form of a network, the longitudinal wires being considerably thicker than the transverse ones. Another well known system is the Hennebique construction, of which the principal novelty is the formation of ferro-concrete piles, a use of the material which is rapidly extending. The advantages of a concrete pile over a wooden one as regards indestructibility are obvious, and it has been found that a ferro-concrete pile can be used under practically the same conditions as a wooden one. Provided the concrete is properly made, it acts as a perfect protection to the metal which it encases, and wholly prevents oxidation or rust. Experiments have shown that the adhesion of the concrete to the metal is equivalent to about 500–600 lbs. per square inch, and since the coefficient of expansion at different temperatures of the two materials is substantially the same, there is practically an unlimited field of usefulness for them.

The manufacture of purpose-made concrete goods, such as paving slabs, sills, concrete sewer pipes, &c., is a use of cement which has been gradually extending for some time past, and the excellent examples of such goods produced by the various firms who make a speciality of that class of work are too well known to need mentioning; the excellent results obtained in this branch of the industry are due entirely to the care which is exercised in selecting and

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thoroughly maturing the cement; the selection, washing and proportioning of the aggregates; and last, but not least, the manipulative skill of the workmen employed. Although it may seem rather a hazardous opinion to express, personal experience has proved that the skill of the workman has more to do with the satisfactory nature of the work than is generally recognised. As a case in point, the concrete work of the sea front or esplanade at two neighbouring watering places was recently carried out with exactly similar materials and with the same brand of cement; yet, owing to superior skill and workmanship, the one is immeasurably superior in finish and appearance to the other.

Without wishing to give rise to the inference that Portland Cement is, so to speak, a hot-house plant that would be irretrievably damaged by rough handling, it is very certain that the greater part of the unsatisfactory work which occasionally occurs, would be entirely avoided if the properties of the material were more thoroughly recognised and appreciated. Cases have occurred more than once in which the cement has been expected to behave in a manner altogether contrary to the laws of nature, viz. to set as quickly in cold weather as in warm, or *vice versâ*, and when these expectations have not been fulfilled, the reputation of the material has suffered accordingly. The author trusts that the more salient properties of Portland Cement which he has endeavoured to place before his readers in these pages will in time come to be generally known and widely appreciated, for he feels convinced that when that period arrives, failures in Portland Cement work will never be heard of, and its value as a constructive material, therefore, considerably enhanced.

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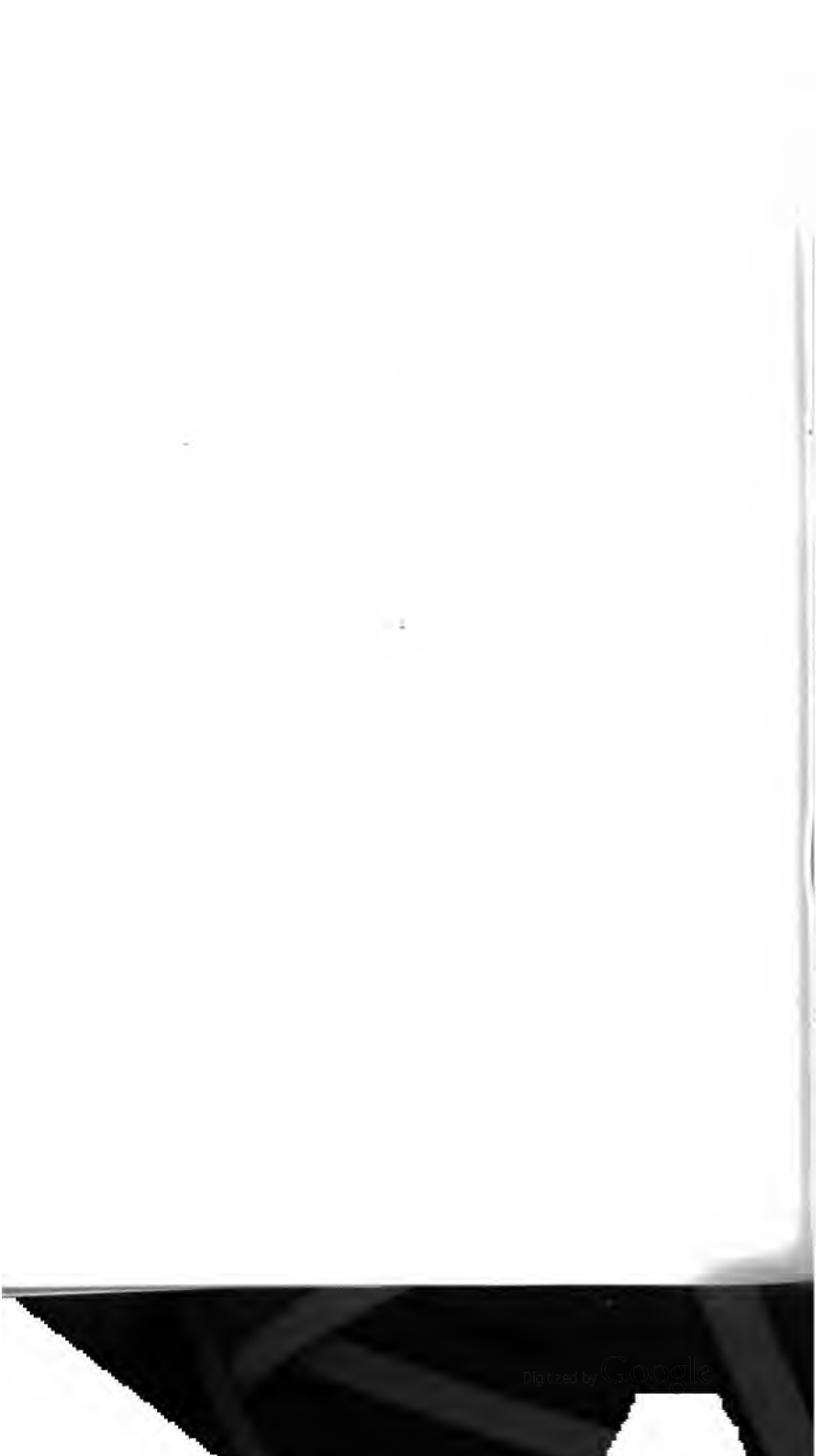
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APPENDIX.

APPENDIX I.

USEFUL MEMORANDA FOR T TESTING ROOM.

1 inch	= 2·5399 centimetres = 25·399 mill
1 foot	= 30·479 „
1 sq. inch.	= 6·451 sq. centimetres.
1 sq. foot	= 929 „
1 cubic inch	= 16·386 cubic centimetres.
1 cubic foot	= 28,315·3 „ = 28·31
1 oz.	= 28·35 grammes = 437·5 grains.
1 lb.	= 453·59 „ = ·45359 kilogra
1 cwt.	= 50·802 kilogrammes.
1 ton	= 1016·04 „ = 1·016 ton
1 centimetre	= ·3937 inches
1 metre	= 39·37 „ = 3 ft. 3·37 inches.
1 cub. centimetre	= ·061 cub. inches.
1 litre	= 61·027 „ = ·0353 cub. ft.
1 cub. metre	= 35·316 cub. ft.
1 gramme	= 15·432 grains = ·03526 ozs. = lbs.
1 kilogramme	= 2·2046 lbs.
1 tonne	= ·9842 tons = 19 cwts. 2 qrs. 21 ll
100 lbs. per bushel	= 1248 grammes per litre = 12 grammes per cubic metre.
	= 77·9 lbs. per cubic foot.
1 cubic foot	= 6·232 gallons.
1 bushel	= 1·284 cubic feet.

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20 × 20	sieve	(=	400	per sq. in.)	corresponds to	64	per sq. cm.
30 × 30	„	(=	900	„)	„	144	„
40 × 40	„	(=	1,600	„)	„	256	„
50 × 50	„	(=	2,500	„)	„	400	„
76 × 76	„	(=	5,776	„)	„	900	„
100 × 100	„	(=	10,000	„)	„	1600	„
180 × 180	„	(=	32,400	„)	„	5000	„
200 × 200	„	(=	40,000	„)	„	6400	„

100 lbs. per sq. in. = 7·031 kilogrammes per sq. cm.

1 kilogramme per sq. cm. = 14·22 lbs. per sq. inch.

400 lbs. per sq. in. = 900 lbs. per $1\frac{1}{2} \times 1\frac{1}{2}$ in. section (i.e. $400 \times 1\frac{1}{2} \times 1\frac{1}{2} = 400 \times 2\frac{1}{4} = 900$).

To convert Fahrenheit to Centigrade:—Subtract 32 and multiply by $\frac{5}{9}$.

To convert Centigrade to Fahrenheit:—Multiply by $\frac{9}{5}$ and add 32.

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APPENDIX II.

RAW MATERIALS.

VARIOUS RAW MATERIALS FROM WHICH POR CEMENT IS MANUFACTURED IN ENGLAN ABROAD.

Analyses by the Author.

CHALK AND CLAY FROM LEWES, SUSSEX.

——	Chalk.	Clay.	(
Water and organic matter	·32	4·28	
Insoluble residue . .	1·57	..	
Silica	·06	65·49	5
Alumina	·25	12·17	1
Oxide of iron . . .		5·15	
Carbonate of lime . .	97·53	10·27	
„ magnesia .	trace	2·37	
Pyrites	..	..	
Alkalies and loss . .	·27	·27	
	100·00	100·00	10

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WHITE CHALK AND CLAY FROM PORTSMOUTH.

——	Chalk.	Chalk.	Clay.
Water and organic matter	·09	·10	8·10
Insoluble residue . .	·68	·80	..
Silica	..	..	65·13
Alumina	·26	·22	12·08
Oxide of iron . . .			2·76
Carbonate of lime . .	98·25	97·89	5·18
„ magnesia .	·61	·71	1·32
Pyrites	..	..	3·09
Sodium chloride . .	..	..	2·11
Alkalies and loss . .	·11	·28	·23
	100·00	100·00	100·00

BLUE LIAS STONES AND SHALE FROM BRIDGWATER.

——	Stone.	Stone.	Stone.	Shale.	Shale.
Water and organic matter	1·11	·79	2·63	2·03	3·65
Silica	13·57	8·76	12·01	31·28	32·10
Alumina. . . .	4·45	3·39	5·79	9·42	11·15
Oxide of iron. . .	1·54	1·40	·80	1·97	2·27
Carbonate of lime . .	73·46	80·91	72·68	49·14	43·19
„ magnesia .	2·58	3·15	2·57	3·21	3·02
Pyrites	2·88	1·29	2·27	·12	1·39
Potash	·41	·31	1·25	1·81	1·85
Soda				·94	·83
Loss				·08	·55
	100·00	100·00	100·00	100·00	100·00

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MATERIALS FROM JAVA.

——	Silica.	Calcareous Tufa.	Limestone.
Water and organic matter .	6·30	·50	..
Insoluble residue . .	..	·98	trace
Silica	69·64	·16	·01
Alumina	13·74	·46	·08
Oxide of iron . . .	2·20		
Carbonate of lime . .	2·62	96·75	98·96
„ magnesia .	2·25	·46	·63
Potash	2·12		
Soda	1·09	·69	·32
Loss	·04		
	100·00	100·00	100·00

MARLS FROM HOLLAND.

——	Marl.	Marl.
Water and organic matter . .	·63	1·99
Silica.	19·16	27·44
Alumina and oxide of iron . .	3·03	4·43
Carbonate of Lime . . .	76·45	65·20
Sulphur, magnesia and alkalies .	·73	·94
	100·00	100·00

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LIMESTONES AND SHALES FROM SPAIN.

——	Stone.	Stone.	Shale.	Shale.
Water and organic matter .	·22	..	8·44	5·54
Silica	2·59	·89	43·37	40·12
Alumina	·79	·30	10·49	4·86
Oxide of iron . . .	·49	·55	4·05	1·30
„ manganese . .	..	·27	..	..
Carbonate of lime . .	94·52	96·91	30·75	45·11
„ magnesia .	1·28	·99	2·08	2·20
Sulphur	..	..	trace	nil
Alkalies and loss . .	·11	·09	·82	·87
	100·00	100·00	100·00	100·00

LIMESTONES AND CLAY FROM ADELAIDE, AUSTRALIA.

——	Limestones.			Clay.
	Blue.	Pink.	Yellow.	
Water lost at 212° F. . .	..	..	..	9·15
Organic matter . . .	..	..	..	3·36
Silica.	3·40	5·38	4·58	53·14
Alumina	2·77	4·04	4·45	19·36
Oxide of iron . . .	1·15	2·22	1·33	5·78
Carbonate of lime . .	91·32	86·79	88·92	3·91
„ magnesia .	1·28	1·55	·96	4·15
Sulphuric acid . . .	trace	..	..	1·09
Alkalies	..	..	..	nil
	99·92	99·98	100·24	99·94

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LIMESTONE AND CLAY FROM JAMAICA.

——	Stone.	Clay.
Water and organic matter . .	..	9·47
Silica	trace	50·68
Alumina	trace	17·79
Oxide of iron	trace	5·35
Carbonate of lime . . .	99·18	11·32
„ magnesia . .	·86	4·91
Alkalies and loss . . .	..	·48
	100·04	100·00

MARLS AND CLAY FROM CANADA.

——	Marl.	Peaty Marl.	Clay.
Water and organic matter.	1·57	29·10	2·16
Silica	·11	1·23	59·45
Alumina	·48	·64	19·97
Oxide of iron . . .	1·75	·87	5·95
Carbonate of lime . .	95·11	67·27	4·66
„ magnesia .	·84	·79	6·74
Alkalies and loss . .	·14	·10	1·07
	100·00	100·00	100·00

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LIMESTONE, CLAY AND SLATE FROM EAST INDIES.

——	Clay.	Slate.	Stone.
Water and organic matter.	3·39	nil	..
Silica	55·71	41·93	7·36
Alumina	13·59	12·03	1·32
Oxide of iron . . .	10·40	6·85	·57
Carbonate of lime . .	11·14	35·64	89·86
„ magnesia .	5·33	2·68	·73
Alkalies and loss . .	·44	·87	·16
	100·00	100·00	100·00

LIMESTONE, CLAY AND ALKALI WASTE FROM CHESHIRE.

——	Stone.	Clay.	Clay.	Alkali Waste.
Water and organic matter .	..	6·16	3·15	·60
Insoluble residue . .	·53	..	..	..
Silica.	..	48·38	49·40	·41
Alumina	..	15·60	16·80	·26
Oxide of iron . . .	..	2·50	5·45	
Carbonate of lime . .	99·32	10·98	10·25	89·59
Hydrate „ . .	..	..	..	7·73
Carbonate of magnesia .	trace	15·88	14·18	..
Sulphuric acid . . .	trace	·25	·56	..
Soda and potash . .	·15	·25	·21	1·08
Loss				·33
	100·00	100·00	100·00	100·00

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——	Chalk.	Cl
Moisture lost at 212° Fahr. . .	..	2
Organic matter	..	4
Silica in form of fine sand . .	..	18
Silica	10·65	39
Alumina	3·10	10
Oxide of iron		5
Lime	46·94	·8
Magnesia	1·03	1
Sulphuric acid	trace	2
Carbonic acid	38·02	6
	99·74	100

LIMESTONE, CLAY AND SHALE FROM NATAL, SOUTH

——	Limestones.		Clay.	Sl
Water and organic matter	2·62	2·78	8·47	8·3
Silica	8·72	6·69	66·51	59·6
Alumina . . .	·70	·46	13·38	20·1
Oxide of iron. . .			4·41	8·3
Carbonate of lime . .	84·63	84·53	3·19	1·8
„ magnesia .	2·99	5·12	2·18	1·1
Pyrites	..	..	·51	trac
Alkalies and loss . .	·34	·42	1·35	·3
	100·00	100·00	100·00	100·0

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LIMESTONE AND CLAY FROM MALAY STATES.

——	Stone.	Clay.	Clay.
Water and organic matter.	nil	10·87	11·31
Silica	..	52·55	54·08
Alumina	·16	30·44	30·93
Oxide of iron . . .		2·85	1·25
Carbonate of lime . .	99·32	1·64	·85
„ magnesia .	·52	·92	1·18
Alkalies and loss . .	..	·73	·40
	100·00	100·00	100·00

LIMESTONE AND CLAY FROM LYME REGIS.

——	Limestone.	Clay.
Water and Organic matter . .	..	13·19
Silica	7·37	20·04
Alumina	3·86	8·70
Oxide of iron	2·15	·60
Carbonate of lime . . .	81·07	48·01
Sulphate „ . . .	2·96	·80
Carbonate of magnesia . .	2·37	1·88
Sulphur (as Pyrites) . . .	..	3·51
Alkalies	·22	1·92
Loss		1·35
	100·00	100·00

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	Stone.	Clay.
Water and organic matter.	·02	19·17
Insoluble residue . .	·65	..
Silica . .	..	39·83
Alumina	..	26·31
Oxide of iron . . .	·33	9·25
Carbonate of lime . .	97·79	2·77
„ magnesia .	·74	1·83
Alkalies and loss . .	·47	·84
	100·00	100·00

LIMESTONE AND SHALE FROM SHREWSBURY.

	Limestone.
Carbonic acid	36·90
Silica	8·51
Alumina	5·11
Oxide of iron	1·55
Lime	45·82
Magnesia	1·87
Sulphuric acid	·20
Alkalies	trace
	99·96

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APPENDIX III.

BRITISH STANDARD SPECIFICATION FOR PORTLAND CEMENT.

ISSUED DECEMBER 1904 BY
THE ENGINEERING STANDARDS COMMITTEE.

Supported by The Institution of Civil Engineers; The Institution of Mechanical Engineers; The Institution of Naval Architects; The Iron and Steel Institute; The Institution of Electrical Engineers.

1. *Quality and Preparation.*—The cement shall be prepared by intimately mixing together calcareous and argillaceous materials, burning them at a clinkering temperature and grinding the resulting clinker. No addition of any material shall be made after burning, except when desired by the manufacturer and if not prohibited in writing by the consumer, in which case calcium sulphate or water may be used. The cement, if watered, shall contain not more than 2 per cent. of water, whether that water has been added or has been naturally absorbed from the air. If calcium sulphate is used, not more than 2 per cent., calculated as anhydrous calcium sulphate, of the weight of the cement shall be added.

2. *Sampling and Preparation for Testing and Analysis.*—As soon as the cement has been bulked either at the manufacturer's works, or on the works in connection with which it is to be used, at the consumer's option, samples for testing shall be taken from each parcel.* Each sample shall consist of cement from at least twelve different positions in the same heap, so distributed as to ensure, as far as practicable, a fair average sample of the whole

* Should the consumer desire to stipulate for any special quantity, the size of the heap must be stated.

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parcel, all to be mixed together and the sample for testing to be taken therefrom.

Before gauging the tests, the sample so obtained shall be spread out for a depth of 3 inches for 24 hours, in a temperature of 58 to 64 degrees Fahrenheit.

In all cases where consignments are of 100 tons and upwards, samples, selected as above from each consignment, either at the manufacturer's works, or after delivery at the works where the cement is to be used, shall be sent for expert testing and for chemical analysis. In no case shall cement so tested and analysed be accepted, or used, unless previously certified in writing by the consumer to be of satisfactory quality. Payment for such tests and analyses shall be made by the consumer, the manufacturer supplying the cement required for the same, free of charge.

The tests and analyses hereinafter referred to shall in no case relate to a larger quantity of cement than 250 tons sampled at one time.

When consignments of less than 100 tons have to be supplied, the manufacturer shall, if required, give a certificate for each delivery, to the effect that such cement complies with the terms of this Standard Specification, with regard to quality, tests and chemical analyses, no payment being made by the consumer for such certificate, nor for the making of such tests and analyses.

3. *Sampling at Manufacturer's Works.*—Should it be deemed more convenient by the consumer that the samples for testing should be taken at the manufacturer's works before delivery, the latter shall, in that event, afford full facilities to the Inspector appointed by the consumer to sample the cement as he may desire at the said works, and subsequently to identify each parcel, as it may be despatched, with that sampled by him. No parcel shall be sent away, unless a written order has been previously received by the manufacturer from the consumer, to the effect that the material in question has been approved.

4. *Fineness and Sieves.*—The cement shall be ground to comply with the following degrees of fineness, viz. :—

The residue on a sieve $76 \times 76 = 5776$ meshes per square inch, shall not exceed 3 per cent.

The residue on a sieve $180 \times 180 = 32{,}400$ meshes per square inch, shall not exceed $22\frac{1}{2}$ per cent.

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The sieves shall be prepared from standard wire, and the size of the wire for the 5776 mesh shall be 0·0044 inch, and for the 32,400 mesh, 0·002 inch. The wire shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

5. *Specific Gravity.*—The specific gravity of the cement shall be not less than 3·15, when sampled and hermetically sealed at the manufacturer's works, nor less than 3·10 if sampled after delivery to the consumer.

6. *Chemical Composition.*—The cement shall comply with the following conditions as to its chemical composition. There shall be no excess of lime, that is to say, the proportion of lime shall be not greater than is necessary to saturate the silica and alumina present.* The percentage of insoluble residue shall not exceed 1·5 per cent.; that of magnesia shall not exceed 3 per cent.; and that of sulphuric anhydride shall not exceed 2·5 per cent.

7. *Mode of Gauging.*—The quantity of water used in gauging shall be appropriate to the quality of the cement, and shall be so proportioned that when the cement is gauged it shall form a smooth, easily worked paste, that will leave the trowel cleanly in a compact mass. Fresh water shall be used for gauging, and the temperature thereof, and that of the test room at the time the said operations are performed shall be from 58 to 64 degrees Fahrenheit. The cement gauged as above, shall be filled, without mechanical ramming, into moulds of the form shown in Fig. A, each mould resting upon an iron plate until the cement has set. When the cement has set sufficiently to enable the mould to be removed without injury to the briquette, such removal is to be effected. The said briquette shall be kept in a damp atmosphere for 24

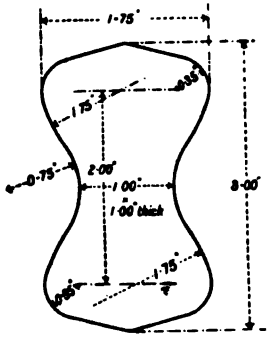

FIG. A.
DIMENSIONS OF BRIQUETTE.

* The proportion of lime to silica and alumina shall be not greater than the ratio represented by $\frac{CaO}{SiO_2 + Al_2O_3} = 2{\cdot}75$.

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hours after gauging, when it shall be placed in fresh water and allowed to remain there until required for breaking, the water in which the test briquettes are submerged being renewed every seven days, and the temperature thereof maintained between 58 and 64 degrees Fahrenheit.

8. *Neat Test.*—Briquettes of neat cement of the shape shown in Fig. A, shall be gauged for breaking at 7 and 28 days respectively, six briquettes for each period. The average tensile

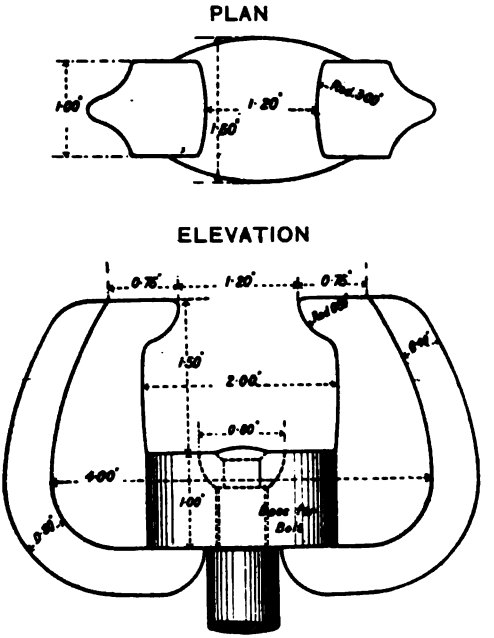

FIG. B.—DETAILS OF JAWS FOR HOLDING BRIQUETTE.

strength of the six briquettes shall be taken as the accepted tensile strength for each period. For breaking, the briquette shall be held in strong metal jaws, of the shape shown in Fig. B, the briquettes being slightly greased where gripped by the jaws. The load must then be steadily and uniformly applied, starting from zero, increasing at the rate of 100 lbs. in 12 seconds. The briquettes shall bear on the average not less than the following tensile stresses before breaking.

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7 days from gauging ... 400 lbs. per square inch of section.
28 „ „ „ ... 500 lbs. per square inch of section.

The increase from 7 to 28 days shall not be less than :—

25 per cent. when the 7 day test falls between 400 lbs. to 450 lbs. per square inch of section.
20 per cent. when the 7 day test falls between 450 lbs. to 500 lbs. per square inch of section.
15 per cent. when the 7 day test falls between 500 lbs. to 550 lbs. per square inch of section.
10 per cent. when the 7 day test is 550 lbs. per square inch or upwards.

9. *Sand Test.*—The cement shall also be tested by means of briquettes prepared from one part of cement to three parts by weight of dry standard sand, the said briquettes being of the shape described for the neat cement tests ; the mode of gauging, the filling of the moulds, and the breaking of the briquettes shall also be similar. The proportion of water used shall be such that the mixture is thoroughly wetted, and there shall be no superfluous water when the briquettes are formed. The cement and sand briquettes shall bear the following tensile stresses :—

7 days from gauging ... 120 lbs. per square inch of section.
28 „ „ „ ... 225 lbs. per square inch of section.

The increase from 7 to 28 days shall not be less than 20 per cent.

The standard sand referred to above is to be obtained from Leighton Buzzard. It must be thoroughly washed, dried and passed through a sieve of 20 × 20 meshes per square inch, and must be retained on a sieve of 30 × 30 meshes per square inch, the wires of the sieves being 0·0164 inch and 0·0108 inch in diameter respectively.

10. *Setting Time.*—There shall be three distinct gradations of setting time, which shall be designated as "Quick," "Medium," and "Slow."*

Quick.—The setting time shall be not less than ten minutes, nor more than thirty minutes.

* When a specially slow setting cement is required the minimum time of setting shall be specified.

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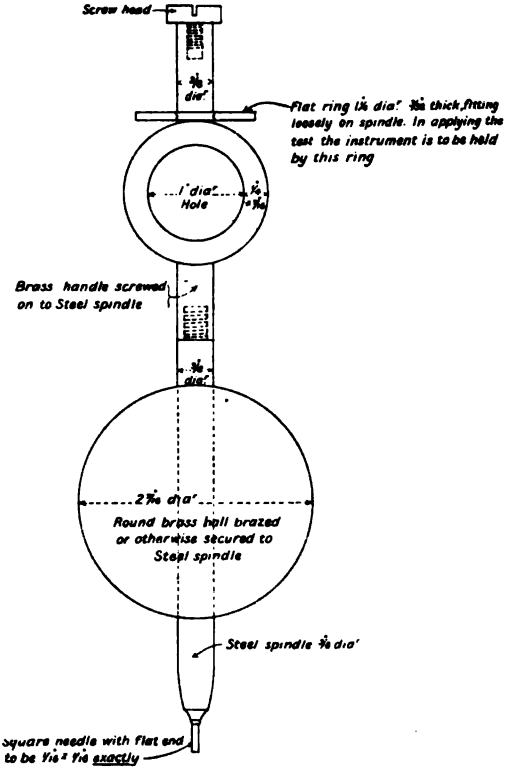
Medium.—The setting time shall be not less than half-an-hour, nor more than two hours.

Slow.—The setting time shall be not less than two hours, nor more than five hours.



Note. 1 The total weight of the instrument, exclusive of the flat lifting ring, must be exactly 2½ lbs
2 The end of the needle must be exactly 1/16 square

FIG. C.

The temperature of the air in the test room at the time of gauging, and of the water used, shall be between 58 and 64 degrees Fahrenheit.

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The cement shall be considered as "set" when a "needle" of the form shown in Fig. C, having a flat end $\frac{1}{16}$-inch square, weighing in all $2\frac{1}{2}$ lbs., fails to make an impression when its point is applied gently to the surface.

11. *Soundness.*—The cement shall be tested by the Le Chatelier

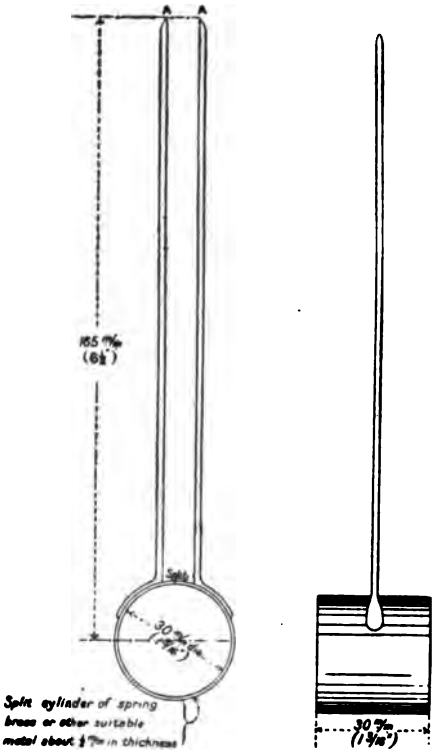

FIG. D.

method, and shall in no case show a greater expansion than 12 millimetres after 24 hours' aeration and 6 millimetres after seven days' aeration.

The apparatus for conducting the Le Chatelier test (Fig. D) consists of a small split cylinder of spring brass or other suitable metal of 0·5 millimetre (0·0197 inch) in thickness, forming

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a mould of 30 millimetres ($1\frac{3}{16}$ inches) internal diameter and 30 millimetres high. On either side of the split are attached two indicators with pointed ends A.A., the distance from these ends to the centre of the cylinder being 165 millimetres ($6\frac{1}{2}$ inches).

In conducting the test, the mould is to be placed upon a small piece of glass and filled with cement gauged in the usual way, care being taken to keep the edges of the mould gently together while this operation is being performed. The mould is then to be covered with another glass plate, a small weight is to be placed on this, and the mould is then to be immediately placed in water at a temperature of 58 to 64 degrees Fahrenheit, and left there for 24 hours.

The distance separating the indicator points is then to be measured, and the mould placed in cold water, which is to be brought to boiling point in 15 to 30 minutes and kept boiling for six hours. After cooling, the distance between the points is again to be measured; the difference between the two measurements represents the expansion of the cement, which must not exceed the limits laid down in this specification.

12. *Acceptance.*—No cement shall be approved or accepted unless it fully complies with the foregoing conditions.

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APPENDIX IV.

GERMAN STANDARD RULES

FOR THE UNIFORM DELIVERY AND TESTING OF PORTLAND CEMENT.

Promulgated July 1887. *Revised February* 1902.

Definition of the term, Portland Cement.

Portland Cement is a product resulting from the burning of an intimate admixture of calcareous and argillaceous materials, as principal ingredients, which burning is carried to the point of incipient fusion, the clinker thus produced being ground to a fine powder.

I. *Packing and Weight.*

Portland Cement shall, as a rule, be packed in casks of standard sizes of 180 kgs. (396 lbs.) gross, and about 170 kgs. (375 lbs.) net weight; and in half casks of standard sizes of 90 kgs. (198 lbs.) gross, and about 83 kgs. (183 lbs.) net weight. The gross weight must be clearly indicated on the cask.

Should the cement be required in casks of a different weight, or in sacks, the gross weight must be clearly marked on the outside.

Leakage or variations in weight of any package of less than 2 per cent. cannot be objected to.

Casks and sacks must also bear the name of the firm, or trade mark of the factory from which it emanated, in distinct characters.

Reasons for I.—The adoption of a uniform weight is urgently necessary in the interest of the purchaser, and also to ensure sound business. A weight of 180 kgs. gross (= about 400 lbs. English), has been selected, that being most commonly used, and almost universally recognised in the commercial world.

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II. *Time of Set.*

Portland Cement can be furnished to set slowly or quickly, according to the purpose for which it is required. Cements which take two hours or more to set, may be described as slow-setting cements.

Explanation of II.—In order to ascertain the time of set of slow-setting cements, take a sample of neat cement and mix for three minutes with water to a stiff paste; for quick-setting cements only one minute's mixing is required. The mixture is then spread on a glass plate, at a single operation, in the form of a pat 1½ centimetres thick (about $\frac{5}{8}$ inch), and tapering towards the edges.

The consistence of the gauged cement should be such that a few taps on the glass plate will cause the mass, which was placed thereon with a spatula, to flow outwards towards the edges. From 27 to 30 per cent. of water is generally sufficient for this purpose. When the pat becomes hard enough to withstand a slight pressure with the finger-nail, the cement may be considered as set.

To ascertain accurately the exact time of set, and to determine the commencement of setting, which is of the greatest importance with quick-setting cement (as it must not be worked after it begins to set), a standard needle of 300 grammes (10½ oz.) weight is used, with a diameter of 1 millimetre (·039 inch) and a flat point. A metal ring 4 centimetres (about 1½ inches) in height, and having 8 centimetres (3 inches) clear diameter, is placed upon a glass plate and filled with gauged cement of the above-mentioned consistence, and tested at intervals with the needle. The exact moment when the needle fails to penetrate the entire depth of the mass is considered as the commencement of setting. The time which elapses between the gauging and the moment at which the normal needle leaves no visible impression on the surface of the pat, is the time taken to set. In order to obtain uniform results in determining the setting of cement, it is of importance to carry out the tests at a mean temperature of both air and water of 15° to 18° C. (59° to 64° F.), as the setting is influenced by the temperature of the air, and of the water used in gauging; a high temperature quickens the setting, a low temperature, on the other hand, retards it.

Slow-setting cements should not materially increase in tem-

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perature during setting, whereas with quick-setting cements a marked increase is permissible. Portland Cement is rendered slower setting by long storage, and its tensile strength is increased if kept in a dry place free from draughts. The opinion frequently prevailing, that Portland Cement deteriorates by long warehousing is therefore an erroneous one, and contract clauses which specify the use of fresh cement only, should be discarded.

III. *Freedom from Expansion and Contraction.*

Portland Cement should be constant in its volume. The decisive test of this property shall be, that a pat of neat cement, made on a glass plate and kept in a damp atmosphere for twenty-four hours, and afterwards immersed in water, shall not show any signs of warping or cracking at the edges, even after the lapse of a considerable period.

Explanation of III.—In carrying out this test, the pat prepared for determining the time of set should be placed under water at the end of twenty-four hours, in the case of slow-setting cements, but in any case only after it has become set. This may be done much sooner in the case of quick-setting cements. The pats, especially in the case of slow-setting cements, must be well protected from draughts, and the direct rays of the sun, until after they have become set. The best method is to place them in a closed box, or cover them with damp cloths. Hair cracks which are caused by shrinkage, due to rapid drying, will thus be avoided. These generally appear in the centre of the pat, and are often mistaken by the uninitiated for cracks caused by blowing. If the cement shows any crumbling, or cracks are visible during the process of hardening while under water, this is a certain indication of the blowing of the cement; that is to say, the cement becomes cracked in consequence of an increase of volume, and a gradual disruption of the particles previously connected takes place, which may ultimately lead to the total destruction of the mass. These symptoms of expansion usually appear within three days, but an observation extending over twenty-eight days is always sufficient.

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IV. *Fineness of Grinding.*

Portland Cement must be ground so fine that not more than 10 per cent. of residue is left after a sample of the same has been passed through a wire sieve of 900 meshes to the square centimetre (5806 per square inch). The thickness of the wire of the sieve should be equal to one-half of the width of the opening of the mesh.

Explanation of and Reasons for IV.—100 grammes (3½ oz.) of cement must be used for each determination. The fineness of grinding of cement is of paramount importance, because, as sand is nearly always used with it, and sometimes in large proportions, the cohesive strength of the mortar is greater in proportion to the fineness of the cement, inasmuch as under those conditions more particles of the cement come into action. It would therefore seem advisable that the fineness of the powder should be uniformly tested by the use of a fine sieve of above-mentioned description. It would, however, be erroneous to judge of the quality of cement by its fineness only, as inferior underburned cements are more frequently found to be finely ground than good hard-burned ones. The latter kind, though coarser, will generally show a higher cementitious value than the former. When cement is to be used mixed with lime, it is advisable to employ hard-burned and extremely finely ground cements; the cost of production is higher, but will be counterbalanced by a materially improved quality of mortar.

V. *Tests for Strength.*

The cementitious value of Portland Cement shall be determined by testing a mixture of cement and sand. The testing shall be carried out in a uniform manner, both as to its tensile strength and resistance to crushing. The test blocks shall be of uniform shape and section, and the same apparatus used in every case.

It is advisable at the same time to ascertain the strength of the neat cement.

The tests for tensile strength should be carried out with briquettes having a sectional area of 5 square centimetres (·77 square inches) at the point of fracture. In the crushing tests

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cubes should be used having sides of 50 square centimetres (7·75 square inches) in area.

Facts in Support of V.—In order to ascertain its cohesive strength, it is advisable to test Portland Cement as a sand and cement mortar, experience having shown that it is impossible uniformly to determine that quality without the addition of sand, especially when it is a question of comparing the cement from different factories.

The testing of neat cement is to be recommended, if it is required to compare Portland Cement with mixed cements and other hydraulic materials, since its high tensile strength and the peculiar qualities of Portland Cement which are wanting in all other hydraulic cements, are thus more distinctly marked than when tested with sand.

Although the relation between tensile and crushing strain varies with different cements, it is usual in many cases to estimate the value of hydraulic cements by their tensile strength only. This, however, leads to an incorrect opinion of their value, as resistance to crushing strain is always the property first to be considered in actual practice, and the only true test as to the strength of the cement is that of compression.

In order to ensure the necessary uniformity in carrying out the tests, it is advisable to employ the apparatus and machines used at the Royal Testing Station at Charlottenburg, Berlin.

VI. *Tensile and Crushing Strength.*

Slow-setting cement, when tested with 3 parts by weight of standard sand to 1 part of cement, must attain after twenty-eight days (that is to say, one day in air and twenty-seven days in water) a tensile strength of at least 16 kilogrammes per square centimetre (227·5 lbs. per square inch). The crushing strength must be at least 160 kilogrammes per square centimetre (2275 lbs. per square inch). With quick-setting cements, the tensile strength at twenty-eight days is generally less than that above mentioned. The time of set should therefore be stated when specifying the tensile strength required.

Explanations.—It is absolutely necessary to use a large proportion of sand in testing, especially when comparing several

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cements, as the power of cementing sand together varies with different cements, and in practice this is the most important feature. The most suitable proportion for this purpose is held to be three parts by weight of sand to one of cement, since with that proportion the cementitious value of various kinds of cement becomes sufficiently developed.

Cement showing a greater relative tensile strength than crushing strength often admits of the addition of a larger proportion of sand, and in consideration of this property, as well as for its greater strength with the usual amount of sand, should command a higher price.

The standard test of strength is the crushing test at twenty-eight days, it being impossible to accurately determine the cementing power, when comparing different kinds of cement, in a shorter period of time. Thus, for instance, the strength of various samples of cement may be alike after twenty-eight days, whereas there may be a material difference between them after only seven days.

The tensile test at twenty-eight days serves as a controlling test of cement delivered. If, however, a decision is to be arrived at after seven days, it may be made with a given sample, after the ratio of tensile strength between the seven days and twenty-eight days has been determined. This preliminary test may also be carried out with neat cement after having ascertained the relation between the strength of the neat cement at twenty-eight days and that mixed with three parts of sand.

It would be of special value in cases where circumstances will admit, to furthur extend the hardening period of the test blocks, in order to ascertain the behaviour of different kinds of cements at long dates.

To arrive at consistent results, sand of the same size of grain and of the same kind should be used in all cases. This normal sand is obtained by washing pure quartz sand as clean as possible, drying it, and passing it through a sieve of 60 holes per sq. cm. (387 per sq. inch) in order to separate the coarser particles; the sand thus obtained is again passed through a sieve of 120 holes per sq. cm. (775 per sq. inch), to free it from the finer particles. The thickness of the wire of the sieves should be 0·38 and 0·32 mm. (·015 and ·013 inch) respectively.

Since all quartz sands do not always give the same results

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when similarly treated, it should be ascertained whether the normal sand employed will give results consistent with the normal sand supplied for testing purposes under the direction of the Committee of the German Cement Manufacturers' Association, and which is also used by the Royal Testing Station of Charlottenburg, Berlin.

Description of the Tests for ascertaining the Tensile Strength and Resistance to Crushing Strain.

As in testing the same cement, a great deal depends on consistent results being obtained at different places, the subjoined rules should be strictly adhered to.

In order to secure accurate results the average of at least ten tests should be made at each date.

Making of Cement-Sand Tests. Preparation of Normal Mortar (1 : 3) *and of the Test Pieces for Strength Tests.*

(*a*) *Mixing of the Mortar.*—The mixing of the mortar of one part by weight of cement to three parts by weight of standard sand shall be carried out as follows, with a Steinbruck-Schmelzer mortar mixing machine. 500 grammes of cement and 1500 grammes of standard sand shall be mixed together dry for half a minute in a mortar with a light spoon. The amount of water previously determined is then to be added to the dry mixture. The moist mass is again mixed for half a minute, then eventually turned into the mortar mixing machine and worked for 20 revolutions.

(*b*) *Estimation of the Percentage of Water.*—The determination of the water is effected by the use of a cube mould in the following manner: The dry mortar in the above specified quantities, is mixed in the mortar mixer as before described, with 160 grammes of water as the first experiment (8 per cent.) and when necessary 200 grammes (10 per cent.) as the second experiment.

860 grammes of the ready mixed mortar, is filled into the cube mould, the filling box of which is provided on the under edge with

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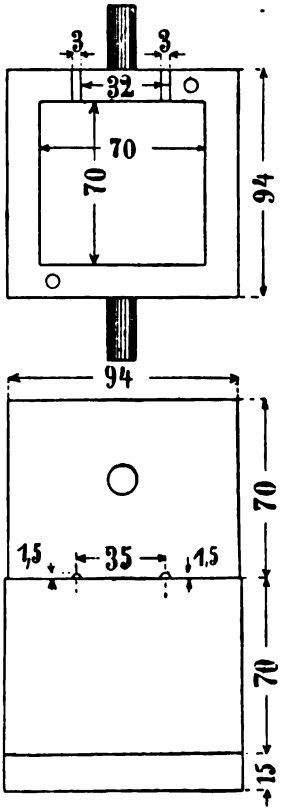
two holes as shown in the sketch, and struck 150 blows with a Böhme hammer apparatus fitted with a Marten's clamp.

According to the state of the mortar during the blows, an opinion can be formed as to which of the above extreme limits of percentage of water is nearest the correct one, whereupon experiments shall be undertaken with different percentages of water.



The percentage of water is correct when, after between 90–110 blows, the liquid cement begins to flow out through both of the holes.

The mean of three test blocks, with the same proportion of water, determines the correct proportion, and this proportion is to be used as the proportion for both tensile and crushing test pieces.

The extrusion of the liquid takes longer when a dry filling box is used than when it has been once used, therefore the result of the first use of the filling box is incorrect. The estimation of the percentage of water by the extrusion of the liquid from the tensile test pieces is unreliable.

(*c*) *Preparation of Test Pieces.*—The preparation of test pieces from normal mortar, for tensile and crushing tests, shall be carried out as follows:—

Of the mortar mixed as previously described, 180 grammes shall be filled into the standard briquette moulds, and 860 grammes into the standard cube moulds, the moulds placed under the Bohme hammer apparatus, fitted with the Marten's clamp, and subjected to 150 blows with the hammer.

The mortar produced from 500 grammes of cement and 1500

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grammes of standard sand is sufficient for the preparation of two briquettes and two cubes.

The test pieces, with their moulds resting on a non-porous bed, shall be covered with a box lined with damp cloth; the briquettes shall be removed from the moulds in about half an hour and the cubes in about twenty hours; twenty-four hours after moulding the test pieces shall be taken out of the box, and placed in water of 15° to 18° C., where they shall remain until due for testing, and shall be tested immediately on being taken out of the water.

Briquettes, &c. of Neat Cement.

Rub the insides of the moulds with a little oil, placing them on a metallic or glass plate (without blotting paper), then weigh off 1000 grammes (35·3 oz.) cement, add 200 grammes = 200 cc. (7·06 oz.) water, and work the mass for five minutes (this is best done with a pestle), fill the moulds, heaping full, and proceed as under (*c*). The moulds, however, must not be removed till the cement is sufficiently hardened.

As in beating in neat cement, briquettes of equal density are required, a very fine or very quick-setting cement will require a correspondingly larger quantity of water.

The amount of water used should always be mentioned in giving the results of such tests.

Treatment of Specimens in Testing.

All the test pieces must be tested immediately after being taken out of water. Since the speed at which the strain is applied has an influence on the result, in testing for tensile strength the increase of weight shall be at the rate of 100 grammes (3·53 oz.) per second.* The average of the ten best results, shall be taken as the tensile strength developed.

In testing for crushing strain, in order to get at a uniform result, the pressure should always be exerted on the side surfaces

* This refers to the speed at which the shot falls into the can of the German standard testing machine (see p. 228), and is equivalent to a strain speed of 661·8 lbs. per minute on the briquette.

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of the cube, and not on the bottom and upper trowelled surface. The average of the ten best results shall be taken as the crushing strength of the sample.

Declaration of the Union of German Portland Cement Manufacturers.

(*a*) The members of the Union of German Portland Cement Manufacturers undertake to bring into the market, under the denomination of "Portland Cement," only a product formed from a mixture of calcareous and argillaceous substances forming the principal ingredients, calcined to incipient vitrifaction, and reduced to a fine powder.

Any material produced by any other method than that stated above, or to which foreign bodies are added either during or before calcination, will not be acknowledged by them as "Portland Cement," but rather, the sale of such products under the term "Portland Cement" will be considered as an imposition on the buyer.

This declaration has no reference to trifling additions made for regulating the setting of Portland Cement, which are allowed to the extent of 2 per cent.

(*b*) Any member acting contrary to the obligation thus undertaken shall be excluded from the Association, and his expulsion made public.

(*c*) The members, in giving this declaration, acknowledge the duty of the Committee of the Union to see that the obligations thus entered into are strictly adhered to.

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APPENDIX V.

FRENCH GOVERNMENT SPECIFICATION.

Issued by the Ministry of Public Works, June 2, 1902.

General Conditions Applicable to All Supplies.

Method of Delivery.—The cement shall be delivered in sacks or in barrels.

The sacks shall contain a net weight of 50 kilogrammes; they shall be sewn on the inside and closed by a lead seal bearing the manufacturer's mark, and in a manner approved by the Administration.

The barrels shall bear on one end the factory mark and on the other the net weight of the cement which they contain.

The sacks and barrels shall be in perfect condition at the time of delivery, and any cement which has been affected by damp shall be rejected.

On the arrival of each delivery the bill of lading or the numbers of the trucks shall be handed to the engineer.

Storage.—The sacks or barrels of cement shall be kept in dry, closed and covered stores; they shall be placed therein in distinct heaps corresponding to each delivery.

The contractor shall have the care and responsibility of the cement in the warehouse until the moment of its use.

Every sack or barrel of cement which is found damaged or of which the covering is not in good condition at the time of delivery shall be rejected.

Tests.—No cement shall be employed before having been submitted to the tests stipulated by the prescribed specification and accepted conditionally.

The engineer shall have the right to re-make, during the storage

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of cement accepted conditionally, the tests stipulated by the prescribed specification, and to reject the deliveries which do not fulfil, at the moment of delivery for use or of final acceptance, the conditions exacted by these tests.

When the tests have given unfavourable results, the contractor may demand that they be repeated at the laboratory of the Ecole des Ponts et Chaussées.

Sampling.—The samples to be submitted to the tests shall be taken at different depths and points, from several sacks, barrels or heaps, selected by the engineer. The cement forming the various samples shall not be mixed.

Quality.—The cement shall be of uniform quality and composition. It shall contain no unburnt or foreign matter.

Fineness.—The tests shall be made on a sample of 100 grammes. The sifting shall be effected by means of sieves of 324, 900, and 4900 holes per square centimetre. The wires of these three sieves shall be of the respective thicknesses of 20, 15, and 5/100 of a millimetre.

Weight.—The weight shall be determined by gently pouring the cement, without shaking, into a metal measure, cylindrical in form, having a capacity of 1 litre and a height of 10 centimetres. The cement contained in the measure shall be weighed; the average results of three successive operations shall be taken as the weight of the sample.

In case of dispute, the filling of the measure shall be effected by means of a funnel containing a sieve of perforated plate having holes of 2 millimetres; this funnel shall be placed in such a manner that the bottom of the tube shall be 5 centimetres above the measure. The cement shall be poured in without shaking or jarring of any kind. When the measure overflows, the material in excess shall be removed by scraping it off with a straight-edge held vertically.

Set.—The cement shall be gauged with potable water into a stiff paste, and shall be made in the form of a pat about 4 centimetres thick, immediately immersed either in fresh water or in sea water according to the conditions of the particular specification adopted. The cement, water, and immersion tank shall be of a temperature of at least 15 deg. Centigrade when it is desired to determine the maximum rapidity of set, and at most 15 deg. Centigrade when it is desired to ascertain the minimum.

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The commencement of set shall be when a Vicat needle having a section of 1 square millimetre and weighing 300 grammes does not wholly penetrate the pat.

The final set shall be the time when the surface of the pat supports the same needle without appreciable penetration, such as a one-tenth millimetre.

In case of dispute, the term "stiff paste" shall be estimated as follows. When gauged in the proportion of five minutes per kilogramme, this paste in a box 4 centimetres deep shall be penetrated to within 6 millimetres of the bottom of the box by a consistence plunger of 1 centimetre diameter and 300 grammes weight.

Tensile Strength.—The tests for tensile strength shall be made on a stiff paste of pure cement and on a plastic mortar of cement gauged with fresh water. They shall be carried out by means of test pieces in the form of a figure 8, having a section in the centre of 5 square centimetres.

The moulds in which the test pieces are to be made shall be filled in one operation; they shall be first shaken to expel air-bubbles, the paste or the mortar shall then be pressed with a trowel but not rammed, then with the edge of the trowel the excess material shall be scraped off and the surface of the test piece smoothed off.

Each test shall consist of the breaking of six briquettes; the tensile strength shall be the mean of the four best results.

The mortar shall be composed of 1 part of cement to 3 of dry sand by weight. The sand shall be composed of equal parts of grains of three sizes, separated by four sieves of perforated iron having holes of $\frac{1}{2}$, 1, $1\frac{1}{2}$ and 2 millimetres in diameter.

The briquettes, after having been kept in damp air and sheltered from draughts and the direct rays of the sun, during the time fixed by the specification adopted, shall be removed from the moulds and immersed in fresh or sea water according to the condition of the specification; in any case, the water shall be renewed every seven days.

In case of dispute, the stiff paste of neat cement shall be that designated by the previous clause, and the plastic cement mortar shall be a mortar composed of Leucate shore sand, furnished by the Administration, and gauged with a quantity of water equal to 1 kilogramme of material to 70 grammes $+ \frac{1}{6}$ P, P being the

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weight of water necessary to make 1 kilogramme of cement into a stiff paste.

Cold and Hot Distortion Tests.—The tests for distortion in the cold shall be made with pats of cement gauged with fresh water into a stiff paste. The pats, being about 10 centimetres diameter and 2 centimetres thick, shall be thinned out on the edges and placed on glass plates; the pats shall be immersed under the conditions stipulated by the specification adopted and kept in water until the cement has been definitely accepted.

None of the pats shall show the least trace of blowing, buckling or bursting; the edges of the pats shall remain firmly fixed to the glass and shall not show any signs of lifting.

The tests for distortion in the hot shall be determined with cylindrical test pieces of a diameter and depth of 30 millimetres moulded in a brass tube, $\frac{1}{2}$ millimetre in thickness, split vertically and carrying, soldered to each end of the slit, a needle of 150 millimetres in length.

Twenty-four hours after being set, these test pieces shall be immersed in water which shall be gradually raised to the temperature fixed by the specification, and maintained at that temperature during the time likewise fixed by the specification; then cooled to the initial temperature. The increase of distance between the points of the needles shall not exceed the figure indicated by the specification adopted.

None of the pats and test pieces shall show the least trace of blowing or distortion, such as cracks, buckling or bursting. The edges of the pats shall remain firmly fixed to the glass without any sign of lifting.

Constancy of Temperature.—The water in which the pats and test pieces are kept shall be maintained at temperatures of between 12 and 18 deg. Centigrade.

Removal of Rejected Cement.—Rejected cement shall be removed from the stores at the cost of the contractor within ten days dating from the official notification of rejection; in default of the contractor conforming to this order, it shall be the duty of the engineer to remove the rejected cement, and this cement shall be removed at the cost and risk of the contractor and placed in stores hired at his expense.

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SPECIFICATION A.

FOR THE SUPPLY OF CEMENT INTENDED FOR SEA-WATER WORK.

Definition.—The Portland Cement shall be produced by the grinding of an intimate mixture of carbonate of lime, silica, alumina, and iron burned to incipient vitrifaction.

Origin and Inspection at the Factory.—The cement shall emanate directly and exclusively from.....

The Administration reserves the right of exercising its control at the factory over the manufacture as well as over the storage and forwarding of the cement which shall be furnished in execution of the present contract.

The Administration shall have the power of installing special permanent inspectors at the factory.

Method of Delivery.—The cement shall be delivered..... ... . (in sacks or in barrels).

Chemical Composition.—The cement shall not contain more than 1½ per cent. of sulphuric acid, 2 per cent. of magnesia, nor 8 per cent. of alumina, nor shall it contain sulphides in weighable quantities.

The index of hydraulicity, that is to say, the proportion between the weight of the combined silica and alumina on the one part, and the weight of lime and magnesia on the other part, shall be at least 0·47 for a percentage of 8 per cent. of alumina with a diminution of 0·02 for each 1 per cent. of alumina below 8 per cent.

Fineness of Grinding.—The cement shall leave a minimum of 40 per cent. of its weight on a sieve having 4900 meshes per square centimetre, and a maximum of 2 per cent. on a sieve of 324 meshes per square centimetre.

Weight.—The weight of a litre of cement shall be at least 1200 grammes.

Time of Set.—Cement immersed in fresh water shall not commence to set in less than 20 minutes.

The set shall be completely finished within a period not less than 3 hours nor more than 12 hours.

Tensile Strength of Neat Cement.—Briquettes of neat cement

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immersed in sea-water after 24 hours shall withstand a resistance to tensile strain per square centimetre of at least:

15 kilogrammes after 7 days
* 30 kilogrammes after 28 days.

The strength developed shall also increase at least 3 kilogrammes from the 7 to 28 days.

Tensile Strength of Cement Mortar.—Briquettes of mortar immersed in sea-water at the end of 24 hours, shall withstand a tensile strain per square centimetre of at least:

6 kilogrammes after 7 days
* 12 kilogrammes after 28 days.

The strength developed shall also increase 2 kilogrammes from the 7 to 28 days.

Distortion in Cold and Hot Water.—The pats and briquettes shall be kept in a damp atmosphere during 24 hours. The pats shall then be immediately immersed in sea-water. The temperature of the test for distortion in hot water shall be 100° Centigrade, which shall be maintained for 3 hours. The increase of the distance between the points of the needle shall not exceed 5 millimetres.

SPECIFICATION B.

For the Supply of Cement not for Use in Sea-Water.

Definition.—The Portland Cement shall be produced by the grinding of an intimate mixture of carbonate of lime, silica, alumina, and iron burned to incipient vitrifaction.

Origin and Inspection at the Factory.—The cement shall emanate directly and exclusively from.....

The Administration reserves the right of exercising its control at the factory over the manufacture as well as over the storage and forwarding of the cement which shall be furnished in execution of the present contract.

* The above figures are the minimum; the engineer can increase them after he has satisfied himself that the manufacturers are able to supply that which he specifies.

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The Administration shall have the power of installing special permanent inspectors at the factory.

Method of Delivery.—The cement shall be delivered..... ..... (in sacks or in barrels).

Chemical Composition.—The cement shall not contain more than 3 per cent. of sulphuric acid, 5 per cent. of magnesia, and 10 per cent. of alumina, nor sulphides in weighable quantities.

Fineness of Grinding.—The cement shall leave at most 30 per cent. of its weight on a sieve of 4900 meshes per square centimetre and 10 per cent. on a sieve having 900 meshes per square centimetre.

Weight.—The weight of a litre of cement shall be at least 1100 grammes.

Time of Set.—Cement immersed in fresh water shall not commence to set in less than 20 minutes.

The set shall be completed within a period of not less than 2 hours nor more than 12 hours.

Tensile Strength of Neat Cement.—Briquettes of neat cement immersed in fresh water after 24 hours, shall withstand a resistance to tensile strain per square centimetre of at least:

25 kilogrammes after 7 days
* 35 kilogrammes after 28 days.

The strength developed shall also increase at least 3 kilogrammes between the 7 and 28 days.

Tensile Strength of Cement Mortar.—Briquettes of mortar immersed in fresh water at the end of 24 hours, shall withstand a tensile strain per square centimetre of at least:

8 kilogrammes after 7 days
* 15 kilogrammes after 28 days.

The strength developed shall also increase at least 2 kilogrammes between the 7 and 28 days.

Distortion in Hot Water.—The test pieces shall be preserved in a damp atmosphere for 24 hours. The temperature of the test shall be 100° Centigrade, and shall be maintained for 3 hours. The increase of distance between the points of the needles shall not exceed 10 millimetres.

* The above figures are the minimum; the engineer can increase them after he has satisfied himself that the manufacturers are able to supply that which he specifies.

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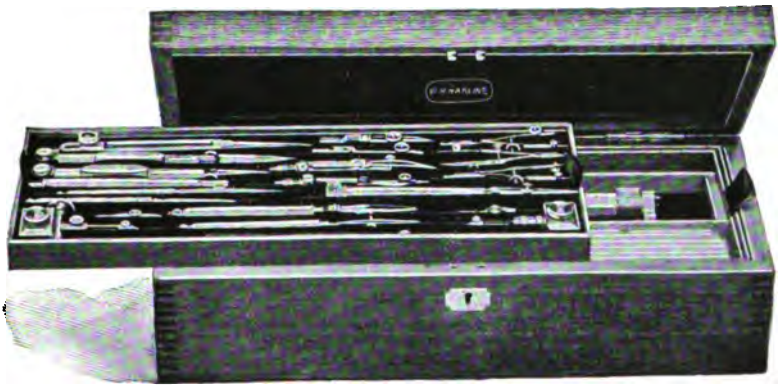

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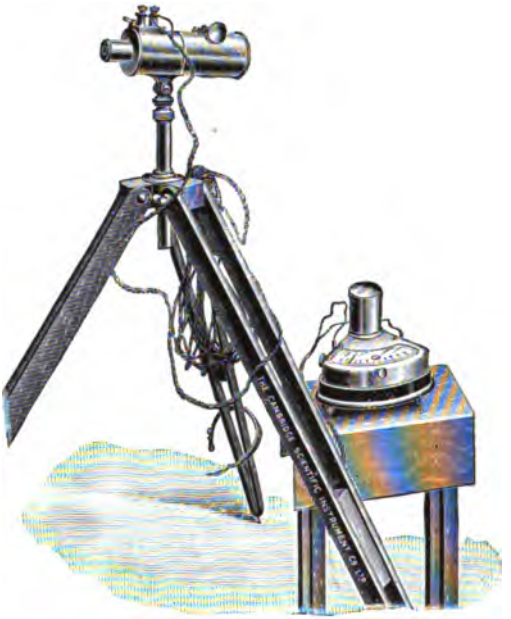

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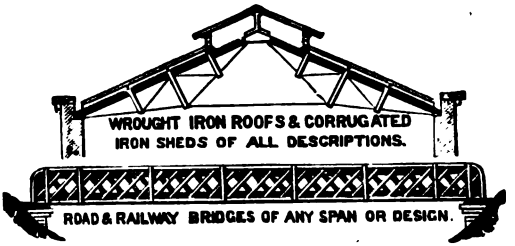

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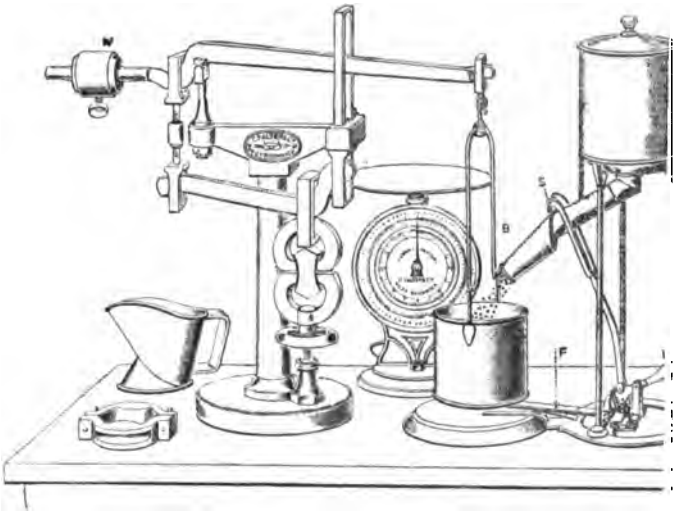

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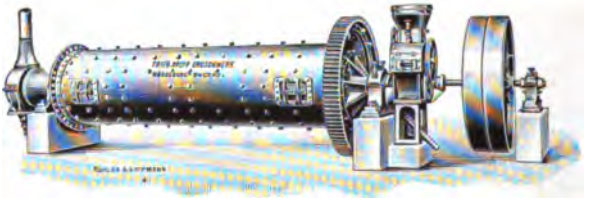

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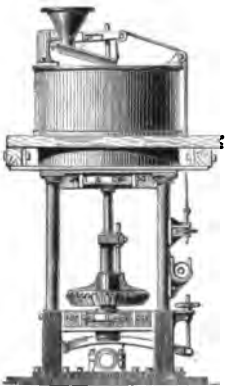

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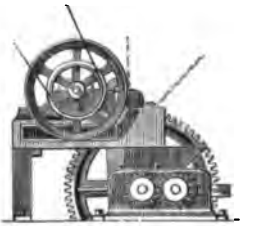

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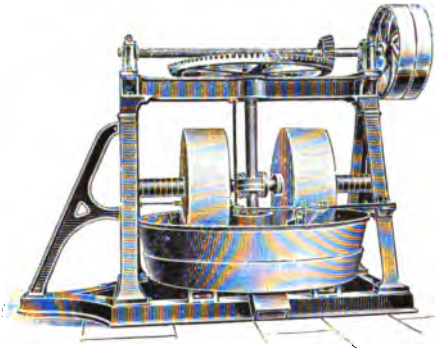

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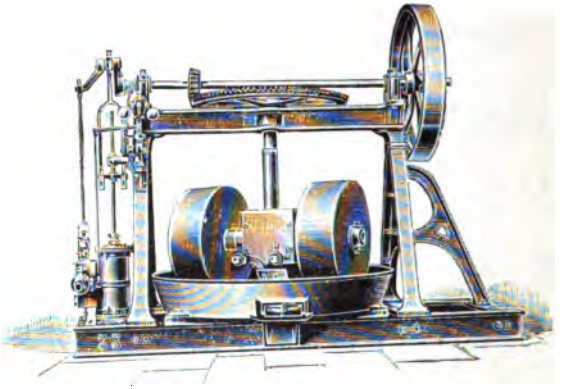

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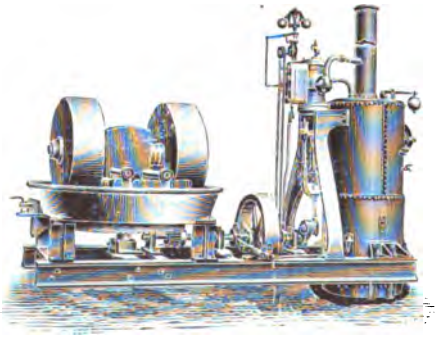

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The Chalk and Clay from which this brand of Cement is manufactured have been analysed by the highest authorities on Portland Cement, and certified to be of the best quality.

Testimonials from Government, London County, Metropolitan Borough, and other Council Contracts; also from Contractors for Reservoirs, Main Drainage, Sea Defence, and many other works.

Works: MURSTON, SITTINGBOURNE, KENT

(Formerly the Murston Branch of the Burham Cement Co., Ltd.).

Telephone:
12, SITTINGBOURNE.

Telegrams:
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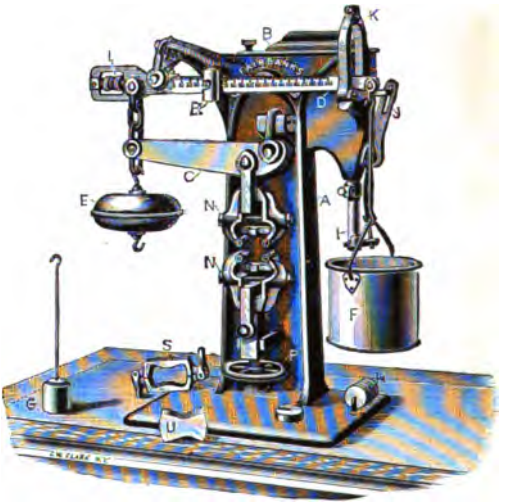
CEMENT TESTING MACHINES

This machine embodies the very latest improvements in design and method of testing. It is very strongly and compactly built with steel levers and brass counterpoises, and is fitted with a new design of roller tip clamps and improved cut-off valve.



No.	Capacity. Lbs.	Size—Base.	List Price.
3182	600	9 in. × 22 in.	£17 15 0
3184	1,000 . ..	12 in. × 24 in.	£23 0 0
3176	2,000	12 in. × 24 in.	£31 5 0

One Mould supplied with each Machine.

Extra Moulds, **16s. 6d.** each. Compression Attachment, **£6 5 0.**

There are no springs, or hydraulic apparatus, the action being automatic and giving uniformly accurate results, as it is entirely free from any vibration or jarring which would tend to break the specimen before its greatest efficiency had been reached. The accuracy, compactness, and convenience of this machine are unequalled.

Write for Descriptive Pamphlet No. 336.

THE FAIRBANKS COMPANY,

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